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ABSTRACT

A learning cycle consists of three phases: exploration; conceptual invention; and expansion of an idea. These phases parallel Piaget's functioning model of assimilation, disequilibrium and accomodation, and organization respectively. The learning cycle perceives students as actors rather than reactors to the environment. Inherent in that perception are three assumptions, that: (1) each of the three phases is necessary; (2) the sequence of phases must be exploration, conceptual invention, and expansion of the idea; and (3) the form of the exploration is student investigation with materials. Seven experiments were conducted to ascertain the impact of each assumption on students' achievement of conceptual understanding of and attitudes toward selected concepts. Concepts and principal variables (assumptions) tested were: physical and chemical change (sequence); conservation of weight and atoms (necessity); simple chemical reactions (form-lesson control); redox reactions (necessity); reaction rates (form-data presentation); heat laws (sequence); and Arrhenius acids and bases (form-lesson control). Among the conclusions drawn are those indicating that the sequence of an activity appears to be important, the laboratory as an instructional format for the learning cycle is effective and highly thought of by students, and that teachers utilizing reading with learning cycles shouldn't expect them to be effective. (JN)

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SEQUENCING LANGUAGE AND ACTIVITIES IN TEACHING HIGH SCHOOL CHEMISTRY

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A REPORT TO THE NATIONAL SCIENCE FOUNDATION

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Foreword

The research which is reported in this volume is an attempt to better understand the learning cycle and its connection to the developmental theory of Jean Piaget. It is the writer's hope that our findings will continue to establish the learning cycle approach as a model for designing curriculum and teaching procedures.

Many persons have contributed to the development of the curriculum materials used in this research. A special acknowledgement goes to Bill Fix who wrote most of the learning cycles used in the chemistry program and Linda Atkinson who along with Bill helped to modify the learning cycles used in this research. Linda and Bill were also truly research partners. They helped to design the achievement instruments and wrote the case study evaluations found in this report.

The writer would also like to thank the students and administration of Norman High School, Norman, Oklahoma. Their continued cooperation with the research efforts of the science education group at the University of Oklahoma is much appreciated.

The writer owes a major debt to his two research partners, Doctor John Renner, University of Oklahoma, and Doctor Howard Birnie, University of Sakatchewan, who spent his sabbatical leave with us. Thanks are also owed to Doctor William H. Graves, University of Oklahoma, who was the project statistical consultant.

Michael R. Abraham
Norman, Oklahoma
October, 1983

CHAPTER ONE

THE LEARNING CYCLE

A generalized teaching model is used in the majority of science classes throughout the United States and Canada and probably the world. In the model the students are first informed of what they are expected to know. The informing is accomplished via a textbook, a motion picture, a teacher or some other type of media. Next some type of proof is offered to the students in order for them to verify that what they have been told is true. In science the laboratory is often used to allow the students to verify that their newly-acquired information is true. Finally, the students answer questions, work problems, balance chemical equations or engage in some other form of practice with the new information. Rarely are additional laboratory experiences provided.

Whether or not "inform-verify-practice" is a proper teaching procedure depends upon how the teacher believes students learn. If the teacher believes that students must be told about (or read about) what it is they are to learn, then "inform-verify-practice" is an appropriate teaching procedure.

There is, however, another belief about how learning takes place. That belief is that the understandings we gain of any concept we develop for ourselves, and that school experiences should provide us opportunities to develop those understandings. One of the most prominent spokespersons for the developmental view of learning was the late Swiss psychologist-epistemologist Jean Piaget.

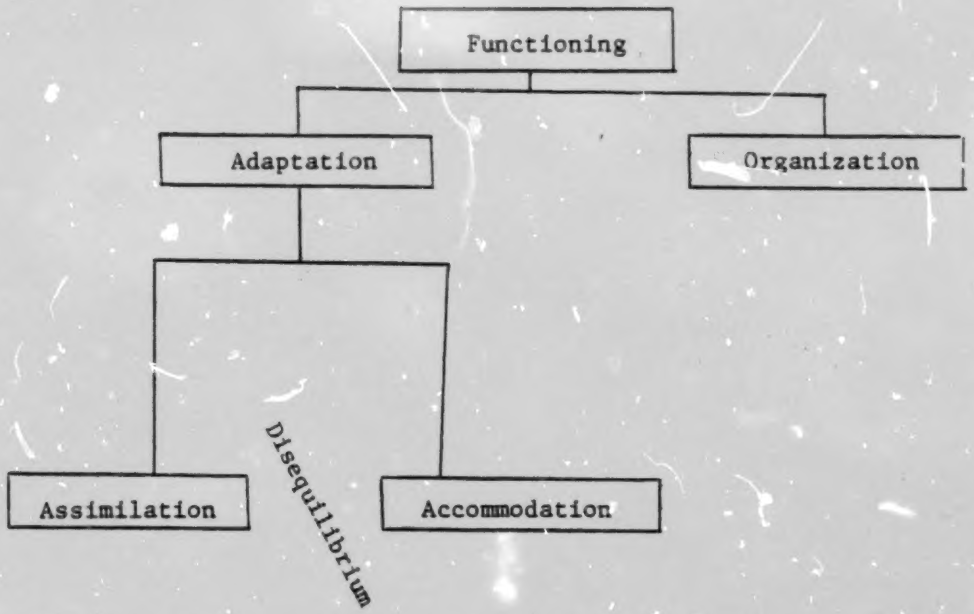
The Developmental Process

At the heart of the Piagetian developmental model, lies the concept of mental structures, which have been called "systems of transformation"(8). We assimilate or transform data from our environment into our existing mental structures. No one can assimilate for us; we must do it ourselves. Our mental structures transform the data assimilated and at the same time accommodate to it.

So our mental structures assimilate or code new data and in the process are changed by those data. The process of change is driven forward by another process which tells us when we are not in balance or equilibrium withour environment. That process is called disequilibration. When our mental structures have accommodated to the assimilated data, we reach a state of equilibration. Equilibration is the process of attaining balance between "external intrusions and the activities of the organism"(4). Assimilation represents an external intrusion and as mental structures attempt to transform it, disequilibrium results. In the process of coming back into equilibrium the mental structures change or accommodate. The process starts with mental structures assimilating, which results in disequilibrium which causes the mental structures to accommodate to the assimilation and end up as changed mental structures. The person having that experience has adapted to the "external intrusion" or stimuli and has made an "accord of thought with things"(6). Disequilibrium--or the desire for equilibrium--is the "energy" that drives the entire process of structure change forward.

But the process is not yet complete. Assume that only one mental structure has been altered by the assimilation-disequilibrium-accommodation-equilibrium chain of events. Prior to its accommodation that structure had an equilibrated relationship with other mental structures; there was a special organization of that thought unit with all other thought units. Now that the thought unit is changed; its organizational pattern is no longer the same. The new structure must be organized with other mental structures and in this process of organization some of the original structures may be changed. Stated another way the organization process represents the "accord of thought with itself"(6).

The process just described may be diagrammed as follows and is referred to as the Functioning model.



The process just diagrammed is, according to Piaget(6), an invariant. That is, it continues to operate in the same fashion building mental structures as long as we interact with our environment. Although Piaget did not, to our knowledge, think of the functioning model as the learning process, it has been helpful to us to consider it as such.

Developmental Stages

According to the Piagetian model, human beings are capable of having four types of mental structures during their lives. Each type of structure represents a unique stage in the intellectual development of a person. The four stages are called sensory-motor, pre-operational, concrete operational, and formal operational. The characteristics of those four unique stages will not be discussed here, but are discussed in several standard sources(3,4,10). Generally, students enter the concrete operational stage at around seven years of age. It has been shown that the level of formal operational thought among secondary school students is not too high(9). Concrete operational students learn concepts from direct (concrete) experience. Research has shown, however, that they do not learn concepts that require abstract and/or hypothetical thought(2,5). The concepts that come from direct experience are called concrete concepts and those which come from hypothetical thought are called formal concepts. Research supports the contention that no teaching approach, including the learning cycle, will cause the learning of formal concepts by concrete operational learners(11).

The Developmental Model and Teaching

If developmental learning occurs as it was outlined in Piaget's Functioning model a teaching procedure can be extracted from it. The model directs that students must first assimilate and that no one can do that for them. In order to assimilate and put their thought in accord with "things" the students need to interact with those "things"; they need to thoroughly explore the "things" about which they are to learn. An exploration activity provides students with the time and opportunity to assimilate data about the concept the teacher wants them to learn. But since the data will be new to the students, their collection and interpretation give rise to many questions such as, "What's this?", "How does this work?", "What does this finding mean?" and so on. Those questions are evidence that disequilibrium is present and that the students are asking for assistance in putting their thoughts in accord with the things they have just explored. In other words, they are ready for accommodation. That evidence of readiness can be used by the teacher to lead the students to consolidate their data and arrive at the concept underlying the entire experience. The teacher and/or the students literally invent the concept from the data. This is also an appropriate time to attach the proper language to the concept.

Following the invention of the concept from the students' data, they should have the opportunity to put this new thought in accord with their other thoughts. The opportunity for the students to expand the meaning, usefulness, and general understanding of the newly-invented concept needs to be available. That is, the student needs to experience the organization phase of the Piagetian functioning model.

We see a definite and direct parallel between Piaget's functioning model and our exploration, conceptual invention, and expansion-of-the-idea teaching procedure. That parallel is portrayed in the following diagram.

Functioning Model	Teaching Model
Assimilation	Exploration
Disequilibrium and Accommodation	Conceptual Invention
Organization	Expansion of the Idea

The teaching model in the diagram we call the learning cycle(1). It is a teaching procedure that is wholly based upon a theory of how learning takes place; it is a developmental theory-based teaching procedure. The learning cycle is fundamentally a method of organizing concept acquisition and problem solving by structured inquiry.

The learning cycle perceives the student as the actor on rather than the reactor to the environment. Inherent in that perception, however, there are--if the learning cycle is to produce the best possible results--three assumptions. Those assumptions are:

1. Each of the three phases is necessary. What happens to student content achievement and attitude toward the discipline and learning if, for example, the learning cycle begins with the introduction of the concept and continues through the expansion phase? Suppose the students experienced only the exploration phase. Would they invent the concept themselves? What kind of language for the concept will be used if students go directly from the activities of the exploration to the activities of the expansion and omit the conceptual invention phase? What type of concept will those students formulate?

2. The sequence of the phases of the learning cycle must be exploration, conceptual invention and expansion of the idea. There are six possible sequences of the three phases of the learning cycle. What influence would any or all of

those sequences have upon student achievement and attitude toward the concept being studied?

3. The form of the exploration phase is student investigation with materials. This seems to be justified by the developmental stage where most secondary students find themselves. The conceptual invention phase is a discussion form. The form of the expansion requires using the concept just invented and its language in an active way--solving problems, doing further experiments, answering questions, and/or reading. Suppose in the exploration phase students were given data that had been collected by someone else instead of collecting it themselves. What impact would that have on conceptual understandings and attitudes toward that concept? How would presenting data through video tape, lecture, and/or readings be received by students? The same questions could be asked about the form of the expansion phase of the learning cycle.

The research reported here tests the three foregoing assumptions about the learning cycle. During the 1981-82 academic year six classes of secondary school chemistry experienced various sequences of a learning cycle, instruction was delivered to them in various forms, and different phases of a learning cycle were eliminated to test the necessity of that phase. In other words, all three of the foregoing assumptions about the learning cycle were treated as variables and experiments were conducted to ascertain the impact of each upon student achievement of conceptual understanding and attitudes toward the concept and the study of chemistry.

Several previous research studies(11,12,13) have compared the learning cycle and the inform-verify-practice models as instructional procedures (see Appendix 1-A). The models were compared on the basis of gains in student understanding of content and intellectual development. These studies judge the learning cycle approach as the more effective teaching procedure. It must be remembered that the research reported in the present study was not concerned with comparing the educational efficacy of the learning cycle and the inform-verify-practice models. All the comparisons made in this report were among the results produced by adjusted learning cycles. The adjustments were made among various forms, sequences, and necessities of the three phases of the learning cycle.

Seven experiments were conducted. Each experiment concerned students learning a specific concept or concepts. The emphasis of each experiment is listed as follows:

Learning Cycle	Concept	Principle Variable Tested
LC-2	Physical & Chemical Change	Sequence
LC-5	Conservation of Weight & Atoms	Necessity
LC-7	Simple Chemical Reactions	Form (Lesson Control)
LC-8	Redox Reactions	Necessity
LC-10	Rates of Reactions (Catalysis)	Form (Data Presentation)
LC-12	Heat Laws	Sequence
LC-14	Arrhenius Acids & Bases	Form (Lesson Control)

During each experiment at least one class was designated as a control group and experienced all phases of the learning cycle in regular form and sequence. The activities of the control groups of each learning cycle were arranged so that their formats were the same throughout all of the seven experiments. That format was arranged as follows.

Exploration Phase (labeled "Gathering Data" on the student handouts): This activity was always an experiment carried out by the students. The students were given no introductory statement concerning the concept, although sometimes it was necessary to instruct them how to use a particular piece of equipment and to inform them of hazards. The laboratory work produced observable data which would eventually (and logically) lead to the concept to be invented later. At the end of instructions which had the students gather data, there were instructions which had the students organize the data into tables or graphs.

Invention Phase (labeled "The Idea" on the student handouts): This phase began with a handout containing questions designed to help the student look for patterns or make sense out of the data collected. These questions were considered by each student. Sometimes small student-led discussions groups were formed to consider the questions. Consideration of "The Idea" questions was followed by a full class discussion led by the teacher. This discussion was divided into three major sections; (1) the teacher and students organized and discussed the data collected by individual students, (2) the teacher and students evaluated various interpretations of the data and developed the concept, and (3) the teacher introduced the language of the concept.

Expansion Phase (labeled "Expanding the Idea" on the student handouts). This phase usually began with a laboratory activity carried out by the students or a demonstration (a class laboratory carried out by the teacher). This activity was carried out along the lines of the Exploration laboratory. The difference between this activity and the Exploration laboratory was that this activity built on an already developed concept and was used to apply, expand, modify, limit, or broaden it. Sometimes the activity was used to relate the new concept to other concepts developed earlier. The laboratory/demonstration was followed by one or more readings which also were used to expand the concept. Depending on the nature of the concept this was followed by questions and problems.

Copies of the student laboratory materials, readings, problems, and questions can be found in the chapter appendices of the chapters devoted to each of the learning cycle experiments (chapters 4-10).

As described earlier, three kinds of learning cycle experiments were completed: sequence, necessity, and form experiments. All three of these types of experiments can be seen as adjustments to the control format described previously. Although combinations of these adjustments could be carried out, the project staff decided to keep each type as simple and distinct as possible.

In the sequence experiments, the three phases of the learning cycle were positioned in different orders. Logically six sequences are possible, and these were tested in LC-2 and LC-12. Because the invention phase of the learning cycle model is based upon data collected in the exploration phase, sequences beginning with the invention phase had to be presented as a lecture, or discussion which provided the information (at a theoretical level) which would have come from the exploration. We recognize that as a consequence the invention phase is not, therefore, a true invention and that this sequence is contaminated with the "form" variable.

In the necessity experiments one phase of the learning cycle was missing. Although, it is possible to design experiments with two phases missing, the project staff decided to limit the study to the effect of each phase. When the missing phase is the exploration, the invention phase will begin the learning cycle. As with the sequence experiments, this situation results in format contamination problems which are unavoidable. The necessity variable was tested in LC-5 and LC-8.

An almost infinite number of form variables could be tested. In the interest of time two key simplifications were made. The first of these was to limit the forms tested to those most commonly found in science classrooms. As a consequence the form variables studied were: student laboratory, teacher demonstration, teacher lecture/discussion, and reading. The second simplification was to keep the form consistent throughout the three phases of the learning cycle. This allowed us to test the effect of a particular form throughout a learning cycle.

Although it may have been interesting (and in some cases more realistic to actual classroom practice) to vary the form from one phase to another, there simply wasn't enough time to try all of these combinations. In order to apply these simplifications two types of form experiments were developed. The first was called the "lesson control" form and kept the focus of the lesson the same in all three phases. This meant that if the exploration was in the form of a reading, so was the invention and exploration. LC-7 and LC-14 were lesson control form experiments. The second type of form experiment was called "data presentation" form and concentrated on the parts of the learning cycle where data was presented. This meant that all of the learning cycle activities which presented data were presented in the same form (e.g. reading). LC-10 was a data presentation form experiment.

One complete chapter of this report is devoted to each of the experiments which was done to test a specific variable; those chapters are four through ten. Also included in the appendix for each chapter devoted to an experiment are the student laboratory materials, teachers guides, demonstrations, lectures/discussions, student readings, problems and questions used for each part of each experiment. The results of the seven experiments are also included in these chapters.

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CHAPTER TWO

EXPERIMENTAL DESIGN AND INSTRUMENTATION

The research was conducted to test the efficacy of the form, sequence and necessity of each phase of the learning cycle. In the seven experiments conducted with the secondary school chemistry group, the regular form and sequence and all phases of the learning cycle were used with at least one of the classes in each experiment. That group was considered to be the control group for that experiment. The control group and experimental groups were assigned by lots. Six classes were available for each experiment, although some of the experiments required only four or five of the classes. The class size ranged from 18 to 27 students with a mean of approximately 23. A detailed discussion of the individual and group characteristics of these students will be taken up in Chapter Three of this report.

Two teachers taught the six classes involved in the research project. One teacher taught three sections (designated sections 11, 14, and 16) and the other also taught three sections (21, 22, and 25). The two teachers planned their lessons together and attended each others classes in order to minimize the teacher variable. In addition these teachers were a part of the research team which planned and developed the curriculum and evaluation materials used by the project.

The curriculum materials used in the project were based on learning cycles first developed in 1974 and revised three times before the beginning of the present research. During the summer of 1981, these materials were revised and reorganized for the purpose of the present research. Eight learning cycles out of the total of 20 were chosen because they best lent themselves to the needs and timing of the research. Additional materials were then developed so that the formats of each learning cycle were identical. This allowed us to have two learning cycles for each of the four types of experiments (sequence, necessity, lesson control form, and data presentation form). Of the eight learning cycles only seven were completed during the 1981-82 school year. The following diagram summarized the control and experimental group assignments for the seven experiments.

	CLASS					
	11	14	16	21	22	25
LC-2 Sequence*	EGI	GEI	IGE	EIG	Control GIE	IEG
LC-5 Necessity*	GE	GI_1	Control GIE		GI_2	IE
LC-7 Lesson Control≠	T_1		R		Control	T_2
LC-8 Necessity*	Control GIE	IE	GI_2		GI_1	GE
LC-10 Data Presentation≠	R	Control	D		D/L	Control
LC-12 Sequence*	EGI	EIG	GEI	Control GIE	IGE	IEG
LC-14 Lesson Control≠	Control	T_1			R	T_2

* The symbols used for the sequence and necessity experiments are as follows: G = gathering data (exploration phase), I = invention phase, and E = expansion phase. If more than one version of a phase is used, it is indicated by subscripts.

≠ The symbols used for the form experiments are as follows: T = teacher, R = reading, D = demonstration, D/L = discussion/lecture.

In order to monitor the various control and experimental groups various techniques and instruments were used. Data were collected by formal pencil and paper tests designed by the project staff for the purpose of evaluating students during each experiment. Two kinds of tests were designed: the CAT tests (content achievement test) which were designed to assess student knowledge of specific concepts, and the BAR surveys which were designed to assess attitude variables of students during a specific activity. A more detailed discussion of these instruments can be found in a later section of this chapter. In addition to these written evaluations, the staff also had access to student grades on classroom handouts and quizzes.

In addition to pencil and paper tests, data were also collected from classroom observation. At least one project staff member attended all of the experimental and control classes. Informal observation notes were kept and all classroom discussions were also taped. These tapes were monitored and consensus observations and conditions were reported. At the conclusion of each learning cycle the participating teachers and observers discussed their observations and reactions to the learning cycle.

Finally, one student was chosen from each class and his/her progress through the learning cycle was monitored as a case-study. Frequent individual interviews were carried out with the case-study student during the lesson. These interviews were also taped. The focus of the class observation and case-study interviews was on concept knowledge and on misconceptions concerning the concept.

Statistical Considerations.

This research produced both quantitative and qualitative data. The results of the repeated administrations of the various forms of the CAT and BAR Tests produced quantitative data that were treated statistically. The results of those treatments are presented in Chapters 4 through 10 which report on the individual experiments.

The statistical treatments generally focused on testing the hypothesis of no difference -- the null hypothesis -- between specific variables. When testing the null hypothesis two types of error are possible. First, the null hypothesis may be rejected when it is true. In other words, one treatment in the research -- say one form of instruction -- is thought to be superior when it is not. That is a Type I error. The educational consequences of this type of error in this research would generally focus on use of personnel time and money. One form of the instruction would be thought to be superior to others and the school would gear up to change to that form. Video tapes, for example, might be made because the statistical tests show that form of instruction to be superior when it is not. In other words, the null hypothesis was rejected when it was true. But any one of the forms of instruction tested would have produced the same results so no educational harm was done; the students learned as much with the video tapes, for example, as any of the other treatments tested. In this research, therefore, Type I error, was not considered as educationally serious.

There is a second type of error that can occur when statistically testing the null hypothesis; the null hypothesis can be accepted when it is not true. False acceptance of the null hypothesis is a Type II error. As an example, consider the ramifications of a Type II error in a form experiment. Suppose that the lecture form was being compared to the regular learning cycle form and because of a Type II error the lecture and learning cycle forms are said to be equivalent treatments when the learning cycle is in fact superior. Because of the extra effort and expense of the regular learning cycle form the laboratory experience for students might be abandoned and the entire theory base upon which the learning cycle is founded would be abandoned. Educational philosophy, classroom utilization, interaction patterns between students and teachers, and the types of learning materials students meet would dramatically change. The entire tenor of the educational environment would be altered. All of the foregoing would have happened when it should not have because the null hypothesis saying there is no difference between the lecture and the learning cycle was accepted when it should not have been. The conclusion we have drawn is that in this research a Type II error is more educationally serious than a Type I error.

A Type I error can be controlled by setting a low value for the rejection of the hypothesis. The lower the level of significance the greater the probability of not making a Type I error. Probability levels of 0.01 and 0.05 are commonly used in educational research. Controlling a Type II error is more difficult but the probability of committing one can be reduced by raising the level of significance for accepting the null hypothesis. After considering the various options and the potential seriousness of a Type II error the staff of the CAPT-S set the level of significance at 0.10.

INSTRUMENTATION

I.Q. Measure. The intelligence quotient (IQ) of each student was measured in September, 1981, with the Otis-Lennon, Mental Ability Test, Form J. Specifically, that instrument measured Deviation IQ (DIQ) which has a mean of 100 and a standard deviation of 16. The reliability of the DIQ was determined by the "corrected split-half correlation and the Kuder-Richardson and alternate forms procedure" (1, p.20). For eleventh graders the Kuder-Richardson and split halves reliabilities are both 0.95 and for twelfth graders those reliabilities are 0.95 and 0.96 respectively.

Measures of Intellectual Development. The theory base of the research is the intellectual development theory of Jean Piaget. That model uses manipulative tasks to assess the individual level of mental operations at which a person is performing. The research of Inhelder and Piaget(3) carefully describes the tasks and delineates student actions and responses which must be present in order to rank that student concrete or formal operational or in transition between those stages. The Piagetian model subdivides concrete and formal thought into two substages, A and B, where the B level designates a higher order of response than does the A level. The original Inhelder-Piaget tasks(3) are administered on an individual interview basis.

Recently at Chelsea College, University of London, a research group headed by Dr. Michael Shayer and known as the Concepts in Secondary Mathematics and Science (CSMS) team adapted the Piagetian interviews to group testing. The group tests are called the Science Reasoning Tasks (SRTs). A description of the SRTs, according to the CSMS team is(2, p.6):

> Science Reasoning Tasks (SRTs) are valid and reliable tests

> for assessing the ability of children or adults to use Concrete and Formal Reasoning strategies. They have a precision comparable with conventional psychometric tests, and they estimate the same abilities which Piaget originally described by individual interview. They can be used by science teachers without professional training in Piagetian studies, and a class of 30 pupils can be tested on each Task in 35-50 minutes.

Through correspondence, Dr. Shayer advised us that two of the SRTs would be sufficient for our purposes. We selected the flexible rods and chemical combinations task. Descriptions of those tasks follow. The most appropriate intellectual development range for each task is 2B to 3B(2, pp.10-11).

> CHEMICAL COMBINATIONS
>
> This task consists of two chemical investigations based on experiments described by Inhelder and Piaget in Chapter 7 of The Growth of Logical Thinking. In the original experiment, pupils were allowed to make mixtures of different solutions. From the appearance, nonappearance, or disappearance of a colour they were asked to make deductions about the nature of the liquids. Their level of thinking was judged from their ability to use combinatorial reasoning, draw valid conclusions and devise appropriate proof strategies. The class task follows a similar pattern, except that the mixtures are demonstrated. While this change restricts one's ability to discover just what mixtures the pupils would make if left to themselves, it also removes the element of chance whereby one pupil will stumble on a particularly revealing mixture, while another, equally intelligent, does not. Thus the group task is more reliable than the individual interview as originally described.
>
> FLEXIBLE RODS
>
> This task based on Chapter 3 of Inhelder and Piaget's The Growth of Logical Thinking investigates the pupil's ability to sort out the effects of five variables which affect the flexibility of metal rods. It tests whether they are aware of the necessity to control variables when conducting experiments, and whether they can apply such a strategy effectively. Their deductive reasoning is tested by seeing how they deduce the effect of the less intuitable variables; cross-section and metal. The last page of the task investigates their ability to handle variables which act in opposite directions to compensate for each other. (In Piaget's language this is Reciprocity).

The foregoing tests were administered in September, 1981, and April, 1982. In addition the Volume and Heaviness SRT was also administered in September,

1981. The range on that task was from pre-operational to Stage 3A. The results of that task were not clear and were not consistent with the other two tasks. Consequently, the Volume and Heaviness task was not re-administered in April, 1982.

The CSMS group used the following equal-interval scale to calculate scores for student performance on the SRTs(2, p.8).

stage 2A	Early Concrete Operational
Less than 2B = 1	Middle Concrete
stage 2B = 2	Late Concrete
stage 2B/3A = 3	Transitional or Mature Concrete
stage 3A = 4	Early Formal
stage 3B = 5	Late Formal Operational

Using the foregoing scoring system, the same 23 students were interviewed by the CSMS group with the task materials and completed the SRTs for the flexible rods and chemical combinations tasks. For the flexible rods the mean scores were 3.78 and 3.61 for the SRT and the interview respectively and for the chemical combinations task the respective means are 4.13 and 4.17(2, p.22). Those scores suggest that the SRTs and the interviews are measuring the same content, that is, the tasks have content validity. The test-retest correlations for the SRTs are 0.64 for chemical combinations and 0.85 for flexible rods. In addition, the Kuder-Richardson internal consistency technique showed values of 0.76 and 0.86 for the chemical combinations and flexible rods respectively.

Group Embedded Figures Tests (GEFT). Earlier research(4) supported by the NSF produced a positive correlation between student performance on the GEFT and level of intellectual development as measured by the Piagetian interview tasks. The GEFT is a measure of an individual's ability to exercise field independence (5, pp.4-10). The GEFT could serve as a useful covariate in studying the relationship between academic achievement and intellectual development and/or IQ.

The reliability of the GEFT has been estimated to be 0.82 using the Spearman-Brown prophecy formula with data from 80 males and 97 females. Those data came from "men and women college students from an eastern liberal arts college..." (5, p.28) and consequently the reliability can serve only as a general guide for the present research. The population we worked with, however, was basically college bound and we concluded that we were justified in considering it reliable with the population of this study.

Concept Achievement Tests (CATs). Content tests were developed for each of the seven experiments in order to assess the students' knowledge of the concept being taught by each learning cycle. As a result of experience with high school students during the pilot for this study (Spring semester, 1981), the project staff felt that students often came up with essentially memorized answers to the questions we asked. During case-study interviews it was discovered that these memorized answers often covered up specific misunderstandings or lack of understanding of the concept. It was also discovered that quantitative questions often elicited formulas and algorithms of which students had little understanding. Several of the consultants to the project suggested that we should use indirect qualitative questions. This way we would not necessarily cue the students on an answer which they remember from class activities. The questions should also ask for an application of the concept rather than request a definition. In a sense, the questions would provide the students with an opportunity to demonstrate a full understanding of the concept without directly asking them to focus on the concept.

The criteria for grading the CATs were based on a method developed by Brumby (11). Each question is assigned a score depending on the level of understanding of the stated concept that is demonstrated by the answer. Points are assigned as follows:

3 = full understanding
2 = partial understanding (i.e. answer is correct and pertinent, but incomplete)
1 = specific misconceptions of the concept
0 = no answer

The overall score on the CAT was calculated by adding all of scores obtained on each question and determining the percentage of the possible points obtained. The specific criteria developed for each test is discussed in the "C" Appendices for Chapters 4-10.

Multiple forms of each CAT test were developed for use in the experiments. In the two sequence experiments, (LC-2, LC-12) three equivalent forms were developed so that the students could be tested at various intermediate points during the learning cycle. Two forms of the CAT were developed for the other experiments. No attempt was made to make these forms equivalent. The "A" form of these tests was used as a pretest to see if students had any previous knowledge of the concept. It was anticipated that students would have no prior knowledge and would therefore have minimal scores on this pretest. If students did have prior knowledge, the pretest might be used as a covariate to avoid any bias favoring one experimental group over another. The "B" form was used as a post-test and a retention test. The "A" form of LC-8 was not used and consequently this learning cycle only used one form. Samples of all of these tests are found in the "C" Appendices for Chapters 4-10.

The reliabilities of each of the CATs were calculated using the Cronbach Alpha test (6). Those values are shown in Table 1-1. Some of the pretests consisted of a single score. Consequently an alpha could not be determined.

TABLE 1-1

Cronbach's Alpha for Each CAT		
LC-2	CAT form A	0.61
	CAT form B	0.56
	CAT form C	0.67
LC-5	CAT form B	0.49
LC-7	CAT form B	0.51
LC-8	CAT form B	0.79
LC-10	CAT form A	0.69
	CAT form B	0.61
LC-12	CAT form A	0.55
	CAT form B	0.67
	CAT form C	0.53
LC-14	CAT form A	0.47
	CAT form B	0.78

Because the CATs were used in a repeated measure design in the two sequence experiments, it was necessary to establish the equivalency of the three forms. Ms. Margaret Kayser of St. Agnus High School in Rochester, New York agreed to help us by using her chemistry classes to cross-validate the three forms of the CAT for these learning cycles. The order in which the students took the three forms of each CAT was varied. Each student took all three forms. The results of the testing are shown in Tables 2-2, 2-3, 2-4, and 2-5.

TABLE 2-2

ANOVA for three forms of the CATs for LC 2

Source	DF	Mean Square	F	P > F
Form	2	1.96	0.29	0.75
Error	32	6.81		

TABLE 2-3

Means for three forms of the CATs for LC 2

Form	Means (raw scores)	Means (% scores)
A	9.18	43.7
B	8.59	40.9
C	9.18	43.7

TABLE 2-4

ANOVA for three forms of the CATs for LC 12

Source	DF	Mean Square	F	P > F
Form	2	2.64	2.64	0.09
Error	30	1.00		

TABLE 2-5

Means for the three forms of the CATs for LC 12

Form	Means (raw scores)	Means (% scores)	Adjusted Means (% score)
A	4.00	44.4	44.4
B	3.63	40.3	44.4
C	4.44	49.3	44.4

From these tables it can be seen that there is no reason to adjust the scores of the three forms of the CATs for LC 2. They will be considered equivalent. However the CATs for LC 12 are not equivalent and will be adjusted by adding or subtracting a constant from the lower and higher score to adjust them. For LC 12 the adjusted scores will be equivalent.

BAR Quick Attitude Inventory. In order to assess the impact of the chemistry taught by the learning cycle, an instrument was needed to measure the students attitudes toward the study of chemistry. The two principal dimensions in which student attitudes toward the effects of various patterns of the learning cycle needed to be assessed were (1) the student's perception of his or her success in understanding the concepts, and (2) the student's perception of his or her feeling toward the investigations and the study of chemistry.

In our research we needed an attitudinal instrument which met the following criteria:

(1) The number of items must be small and the time required for the students to complete the test short (a few minutes).

(2) The items must be selected to measure attitudes toward a single teaching unit or investigation or topic as opposed to general attitudes toward chemistry.

A search of the literature revealed that no attitudinal instruments were available which satisfied these criteria.

In the development of an attitudinal instrument, the decision was made to modify pairs of polar adjectives using the semantic differential as developed by Osgood, Suci, and Tannenbaum (7). The pairs selected were designed to contribute to the two dimensions previously defined. Polar adjectives became polar phrases to better fit the topic.

The Chemistry group used three slightly different versions of the scale as it was developed with LC-5 through LC-14. No instrument was available for use with LC-2. Examples of the various forms of the Birnie-Abraham-Renner Quick Attitude Differential or BAR, as the instrument is named, is found in Appendix

2A. Note that the instructions to the students were slightly modified for each learning cycle. Students were encouraged to write comments on the back of each BAR sheet. Each comment was classified into the categories indicated on the form found in Appendix 2B. The results of each BAR evaluation will be discussed in chapters 4-10.

The following procedures were employed to establish the validity and reliability of the BAR. Where attitudes are concerned, bipolar adjective or phrase pairs with high evaluative loadings are often appropriate, although the selection of polar adjectives or phrases on simply their "face value" for a given situation is acceptable. To the extent that the bipolar adjectives or phrases of the BAR match or are similar to those of Osgood, Suci, and Tannenbaum, their factor loadings are already well established (7).

To quote Van Dalen (8), "When checking content validity, the test constructor alone and with the aid of others judges the extent to which the test items present a representative sample of the universe of the content that the test is designed to measure." The six project members agreed that the BAR appeared to be composed of the items which would measure, among other things, academic and emotional attitudes.

An attitude is defined as a learned, emotionally toned predisposition to react in a consistent way, favorable or unfavorable, toward a person, object, or idea (9). The BAR was constructed to obtain a measure of the student's attitudes toward his comprehension of the concepts and his contentment with his study of the concepts in each investigation. Although the panel judged the BAR to be content valid, the relevance of bipolar adjective or phrase pairs to evaluate particular concepts can only be verified empirically.

The construct validity of the BAR Quick Attitude Differential was carried out using factor analysis. Three marginally different versions of BAR were used during the six learning cycles. The first version of the test was given to physics students following Physics Investigation 4, Experiment 2, and modifications, adjustments and corrections were made to the test items and instructions (See the Physics Report in a companion volume to this report). The revised format was then utilized in all of the other Physics Investigations, 3 through 7 in the physics portion of the study and with slight additional revisions in the chemistry portion of the study.

Seven separate factor analysis procedures using varimax rotation (Nie, N.H. et al, 1975) to determine the principal factors of the BAR were carried out. The factor loadings and communality estimates for these procedures are shown in Table 2-6. The percentage of the variance explained by each factor is also shown in Table 2-6. The factor analysis of two of the physics investigations and five chemistry investigations produced a consistent two-factor solution which accounts for approximately 50% of the variance. No factor structure was found in LC-12.

The common item structure of the two factors is charted in Table 2-7 and may be summarized in the following manner:

Factor 1: includes 1-pleased; 2-satisfied; 4-enthusiastic; 8-liked the topic; 11-activities in order.

These test items are related to the dimension which Osgood, Suci, and Tannenbaum (1957) call evaluative and gain validity from this relationship. Since they seemed to measure the degree of contentment with the particular investigation we called the factor the contentment factor.

Factor 2: includes 3-not confused; 5-easy; 6-nothing new; 7-too slowly; 9-words understood; and 10-solve problems or answer questions.

These items or scales refer to the student's perception of his academic progress toward understanding the concepts of the investigation and thus measure the comprehension dimension of his attitudes. Some of these items are related to

TABLE 2-6

FACTOR STRUCTURE LOADINGS OF THE ITEMS OF THE BAR QUICK ATTITUDE DIFFERENTIAL FOR SEVEN EXPERIMENTS

	PHYSICS						CHEMISTRY														
	EXPERIMENT 3			EXPERIMENT 4			LEARNING CYCLE 5			LEARNING CYCLE 7			LEARNING CYCLE 8			LEARNING CYCLE 10			LEARNING CYCLE 14		
Factors 1 and 2 Communality	1	2	C	1	2	C	1	2	C	1	2	C	1	2	C	1	2	C	1	2	C
1. Pleased	.92*	.13	.85	.85*	.39	.88	.85*	.13	.73	.77*	.36	.69	.73*	.41	.70	.79*	.38	.77	.84*	.31	.80
2. Satisfied	.89*	.25	.85	.79*	.35	.74	.78*	.21	.66	.74*	.39	.69	.74*	.35	.67	.76*	.36	.71	.81*	.33	.77
3. Not confused	.35	.76*	.70	.24	.79*	.69	.43	.70*	.68	.30	.75*	.65	.47	.67*	.67	.44	.71*	.70	.48	.73*	.77
4. Enthusiastic	.69*	.18	.51	.62	.34	.50	.65*	.27	.50	.74*	.06	.55	.75*	.10	.57	.70*	.07	.49	.79*	.09	.64
5. Easy	.23	.64*	.46	.20	.58*	.38	.37	.58*	.47	.18	.76*	.62	.36	.68*	.59	.28	.61*	.45	.38	.65*	.56
6. Nothing new	.30	-.27	.35	-.27	-.02	.67	.28	-.48	.31	.19	-.34	.15	.08	-.51*	.27	.11	-.60*	.37	-.17	.50*	.28
7. Too slowly	.24	-.60*	.68	.07	.59*	.61	-.02	-.55*	.30	.04	-.66	.43	.17	-.45	.23	-.11	-.67*	.46	.19	.58*	.37
8. Like topic	.31	.13	.11	.16	.50	.28	.56*	-.06	.32	.64	.21	.45	.81*	-.08	.66	.69*	.19	.51	.69*	.18	.50
9. Words understood	.26	.69*	.55	.18	.77*	.62	.42	.55*	.48	.18	.57*	.35	.41	.48	.40	.51	.53*	.54	.35	.65*	.54
10. Solve problems	.35	.73*	.66	.22	.72*	.57	.47	.70	.71	.16	.79*	.65	.46	.65*	.63	.34	.70*	.61	.29	.82*	.76
11. Activities in order	.45*	.38	.16	.81*	.13	.08	.42	.27	.25	.46	-.03	.21	.57*	.16	.35	.51	.09	.27	.69*	.19	.50
12. Topic understood	.48	.67*	.41	.30	.72*	.36	.60*	.47	.58	.39	.47	.37	.48	.54*	.53	.55	.39	.45	.41	.67*	.62
Percentage of Variance Explained	26	26		30	23		28	22		24	24		32	20		30	23		31	28	

TABLE 2-7
BAR QUICK ATTITUDE DIFFERENTIAL
SUMMARY OF FACTOR STRUCTURE LOADINGS
FOR PHYSICS AND CHEMISTRY

	Physics		Chemistry						Overall
	EXP 3	EXP 4	LC5	LC7	LC8	LC10	LC12	LC14	
1. Pleased	1	1	1	1	1	1		1	1.
2. Satisfied	1	1	1	1	1	1		1	1.
3. Not confused	2	2	2	2	2	2		2	2.
4. Enthusiastic	1	1	1	1	1	1		1	1.
5. Easy	2	2	2	2	2	2		2	2.
6. Nothing new					2	2		2	2.
7. Too slowly	2	2	2	2		2		2	2.
8. Like topic		2	1	1	1	1		1	1.
9. Words understood	2	2	2	2		1,2		2	2.
10. Solve problems	2	2	2	2	2	2		2	2.
11. Activities in order	1	1			1	1		1	1.
12. Topic understood	2	2	2		1	2		1	2.
13. Taught interestingly				1	1	1			

what Osgood, Suci and Tannenbaum (7) call activity. Factor 12 - Topic understood, loaded on both factors and was half assigned to each. Factor 13 - Taught interestingly, was not used in all of the BARs and was not used in analysis results.

The items listed under each factor provide a definition or description of the factor and these definitions describe the two principle areas of attitude which we set out to measure. The factor analysis thus provides construct validation for the BAR.

Using ANOVA the two BAR factors were used to test for differences among groups in each of the Learning Cycles except LC-2. Results are reported in Chapters 5-10.

In addition to taking the BAR after each Learning Cycle, the students were also encouraged to put written comments on the reverse side of the BAR form indicating how they felt about the Learning Cycle activities. Many students took advantage of this. Their responses were coded on a comment sheet a sample of which can be found in Appendix 2 B. Each comment was judged positive, negative, or neutral and categorized as to the part of a lesson it referred. The number of comments which indicated various general attitudes were also tallied.

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CHAPTER THREE

CHARACTERISTICS OF THE SUBJECTS

In order to better interpret the actual experimental data gathered in the project, an analysis of the abilities of the students in each of the six chemistry classes is necessary. In this chapter we will compare the following variables: age, performances on the three Science Reasoning Tasks (SRTs) (VH, FR, CC), overall Piagetian score taken at the beginning of the course (BPIAG) and then at the end of the course (APIAG), the grades for each of the four quarters given by the teachers of the students and then an overall grade point average, the total IQ score (TIQ) and, the Group Embedded Figures Test (GEFT) score.

Since the SRTs indicate cognitive levels (3B, 3A, etc.) a numeric system was devised for the computation of class averages on the tasks. Six points correspond to a cognitive level of 3B, five points were awarded for a 3A score, four points were given for a 2B/3A score, and three points were marked for a 2B score.

The grade point averages were figured on a four point scale with a 0 corresponding to an F score and a 4 corresponding to an A score. A score was reported for each of the quarter grades. An overall grade point average was also calculated (GPA). Appendix 3A contains the descriptive information described earlier for each individual student by I.D. number. Table 3-1 contains descriptive information by class, teacher group, overall, and gender.

The purpose of the following discussion is to characterize the classes, teacher groups, and students involved in the chemistry experiments. In addition to this, the discussion will attempt to identify any differences between classes and teacher groups on each of these important variables, in order to adjust statistically for any covariance in the following research.

TABLE 3-1: DESCRIPTIVE INFORMATION OF SAMPLE

BY OVERALL, TEACHER, CLASS, AND SEX

	Overall	Teacher		Class						Gender	
		1	2	111	114	116	121	122	125	F	M
TIQ	113	113	112	110	115	115	114	114	108	112	113
GPA	2.82	2.91	2.74	2.94	3.00	2.82	2.84	2.93	2.44	2.95	2.70
GEFT	12.3	12.5	12.2	12.5	13.7	11.6	13.2	12.8	10.7	12.3	12.4
BPIAG	4.61	4.63	4.58	4.61	4.70	4.59	4.81	4.52	4.38	4.52	4.69
APIAG	[illegible].96	4.90	5.02	5.05	4.91	4.74	5.33	5.07	4.53	4.84	5.07
Age	16.5			16.6	16.4	16.3	16.6	16.6	16.5		
G1	3.21	3.23	3.19	3.14	3.44	3.16	3.33	3.33	2.92	3.29	3.12
G2	3.02	3.12	2.93	3.23	3.17	3.00	2.96	3.04	2.81	3.12	2.91
G3	2.62	2.86	2.40	3.00	2.72	2.81	2.73	2.50	1.96	2.77	2.47
G4	2.59	2.69	2.49	2.54	2.94	2.67	2.50	2.78	2.21	2.68	2.49
VH	3.72	3.62	3.82	3.50	3.80	3.58	4.04	3.95	3.50	3.51	3.95
FR1	4.56	4.52	4.60	4.45	4.30	4.76	4.72	4.87	4.18	4.51	4.61
CC1	4.70	4.79	4.63	4.83	5.10	4.48	4.85	4.29	4.68	4.58	4.83
FR2	4.75	4.75	4.75	4.87	4.65	4.72	5.12	4.81	4.27	4.62	4.88
CC2	5.13	5.05	5.20	5.29	5.22	4.70	5.25	5.33	4.94	5.01	5.22

The before Piagetian score and the after Piagetian score are composite scores calculated from the flexible rods and chemical compositions scores obtained during the study. The composite score for the before Piagetian task was calculated by adding the flexible rods 1 task with the chemical compositions 1 task and then dividing by 2 in order to have an average before Piagetian score. The after Piagetian score was similiarly calculated from the flexible rods 2 and Chemical Compositions 2 scores.

Overall Characteristics

The average student in the chemistry portion of this research is 16.5 years old, has an I.Q. of 113, a Group Embedded Figures Test score of 12.3, a before Piagetian score of 4.61 and an after Piagetian score of 4.96. Their overall grade point average is 2.82. The grades were higher during the beginning part of the year and decreased as the course work material became more difficult during the passage of time.

Compared with the physics students (described in the companion volume to this report) the students in chemistry, having taken their course during the junior year, are slightly younger. The physics students are a more select group and have higher average I.Q.'s. The physics group also seem to have a higher proportion of formal operational students as evidenced by their average pretest scores on the volume-heaviness task, the flexible rods task, and the chemical combinations task. Their scores for the post-test are also higher with the exception of the Chemical Composition scores, which are about the same for both the chemistry and physics groups. This brings up the question of familiarity with the context of the chemical combinations task. Since the chemistry group has studies solutions and chemical tests associated with combinations of chemical substances, this information is available to aid them in artificially doing better on the chemical combinations task as a post-test.

In spite of this, perhaps the most significant comparison for the purpose of this research is the significantly larger proportion of concrete operational and transitional students in the chemistry group when compared to the physics group.

Teacher Group Characteristics

The subjects in this research were divided into six classes. Three of which were taught by one teacher and three of which were taught by another teacher. The two teachers who were involved in the instruction were part of the team that planned the research, wrote the curricula used in the research, and planned their lessons and procedures for teaching together. These teachers also were part of the research team that helped write the Cognitive Analysis Tests and helped to grade the tests at the end of the school year.

Table 3-2 has summaries of teacher differences for a number of critical variables including grade point average, before and after Piagetian scores, I.Q., and Group Embedded Figures Tests. Using 0.10 level of significance, it can be shown that there is no teacher differences in any of these variables. Taking this information into consideration, a good case can be made for the idea that there is no differences between the teachers' in these variables and that therefore, the two teacher groups can be considered to be equivalent when making comparisons between classes. In summary, it will be assumed that there is no teacher effect in evaluating the data for the research.

Class Section Characteristics

It must be assumed for the purposes of doing research where classes make up treatment and experimental groups, that the classes are somehow equivalent to each other in so far as the variables associated with the research is concerned. Unfortunately, the social and academic characteristics of classes very often are associated with what might be called a class personality, and as most classroom teachers can tell you all classes are different. Table 3-3 summarizes a number of the variables that were measured for each of the subjects in each of

TABLE [illegible]-2: TEACHER DIFFERENCES

SOURCE	DF	MEAN SQUARE	F	P
GPA				
Teacher	1	1.17	1.18	0.28
Error	153	0.99		
BPIAG				
Teacher	1	0.07	0.09	0.76
Error	123	0.81		
APIAG				
Teacher	1	0.42	0.67	0.42
Error	114	0.63		

Teacher	N	Mean	S.D.	T	P
TIQ					
1	63	113.4	13.6	0.58	0.57
2	75	112.1	12.7		
GEFT					
1	61	12.5	4.2	0.44	0.66
2	75	12.2	4.3		

the six classes used in the chemistry research. As can been seen from that table there is no evidence indicating that the classes are different from each other in so far as grade point average, I.Q., and the Group Embedded Figures Test is concerned. This means that the classes are equivalent to each other in so far as these general measurements are concerned. It is also true that the Piagetian tests given at the beginning of the year shows no evidence of differences between the class. However, the Piagetian test given during the end of the year does indicate a significant difference between the various groups. A Newman-Kuels analysis of the means shows class 21 to have higher scores than class 25.

Since this after Piaget test indicates the developmental level of the students at the time when they were concerned with learning cycles 8, 10, 12, and 14, it is felt that perhaps it would be necessary to use these after Piagetian scores as a covariant in the lessons stated or do a two-way analysis of variance using the after Piagetian test score as a variable. The actual approaches and rationale is discussed in more detail in the chapters associated with those learning cycles. In summary, with the exception of the after Piagetian score it appears that the general characteristics of the students shows no significant difference between classes.

However, there does seem to be some differences associated with the specific knowledge of the individual learning cycles themselves. From data summarized in the following chapters, learning cycles 2 and 7 have differences among the classes on the pre-test. Some adjustment or explanations must be used in interpreting the data from the experiments involving these groups. These adjustments will be discussed in the appropriate chapter involved with each of the learning cycle experiments. There are however difficulties in interpretation involved with using pre-tests as covariants. The question arises as to whether the gain score can be used as an accurate measurement of how much learning has taken place. Obviously,

TABLE 3-3: ANOVA OF CLASS DIFFERENCES

SOURCE	DF	Mean Square	F	P
TIQ				
Class	5	181	1.06	0.39
Error	132	171		
GPA				
Class	5	1.01	1.02	0.41
Error	14[illegible]	0.99		
GEFT				
Class	5	29.5	1.68	0.14
Error	130	17.6		
BPIAG				
Class	5	0.48	0.59	0.71
Error	119	0.82		
APIAG				
Class	5	1.47	2.48	0.04*
Error	110	0.59		

if a class starts with a higher score they don't have as much to learn as a class that may have started with a lower score. So the question of equilibrating the scores in the first place is a questionable procedure. More discussion of this point will take place in the appropriate chapters.

At this point it seems appropriate to discuss the characteristics of each class group. Class 11 was composed of 18 male and 9 female students. The average age of the 27 students as of September 1, 1981, was 16.6 years. The mean grade point average of the class was 2.92 on a four point scale. The class average I.Q. was 110 with the scores ranging from 89 to 125. The mean class score on the SRT composite of the flexible rod task and chemical compositions task, which consist of the before Piagetian score was 4.61 and the after Piagetian score was 5.05. Of the 17 students for which we have scores, 12 were concrete and 5 were formal using a score of 4 as a break even point on the ART test. The teacher of the class made the following statement associated with this group, "Class 11 was my first class of the day. Therefore the behavior of the students was rather low-key. They were a friendly group of students and always wanted to start the day with a joke or story. In the laboratory there was a great deal of interaction between the groups, both social comment and comparison on lab results. During class discussions there were 7 to 10 students who would always ask thought provoking questions. There was one student who complained continuously in a semi-joking manner. At times I felt like this affected the attitude of the class. Overall I felt this class was involved in the course and enjoyed learning."

Section 14 was the smallest class of the chemistry group, containing 14 males and 8 females. Of these 22 students the average age was 16.4 as of September 1, 1981. The mean grade point average was 3.00 on a four point scale. The class I.Q. was 115 ranging from 91 to 140. The mean class score on the SRT Piagetian tests given at the beginning of the course was 4.70. The after Piagetian score was 4.91. At the beginning of the class 13 of the students who we measured were concrete and 7 were formal. The teacher of this class made the following statement concerning this class, "Class 14 met during the early lunch hour. Due to the time of day their behavior was rather slow and unhurried. In comparison to my other classes (Class 11 and 16) there was not very much social interaction among the students. Even in the laboratory they would stay at their own laboratory stations and do their own work. It was a small class. Academically the class was very capable and would become quite involved in the invention discussions. There were many times they would go back to the laboratory and repeat experiments before coming to a conclusion. In general, the class was interested in chemistry and tried to do well in the course."

Class 16 was composed of 29 students, 12 male and 17 female. The average age of the students in the class on September 1, 1981, was 16.3 years. The mean grade point average at the end of the school year was 2.82 on a four point scale. The average I.Q. of the class was 115 ranging from 81 to 150. The before Piagetian score was 4.59 and the after piagetian score was 4.74. Of the 22 students for which we have scores, 16 were concrete and 6 were formal at the beginning of the school year. The following statement was made by the instructor of the class, "Class 16 was my largest class and met the last hour of the school day. It may have been the combination of students or the time of day, but this class was quite gregarious and boisterous. During laboratory activities and class discussions there was a large amount of outside conversation occurring. Academically the class was very diverse, from the very academically inclined down to those who really had a difficult time with the content of the course. The attitude of the students were as varied as the abilities. This class at times had very stimulating discussions."

Section 21 was composed of 11 males and 19 females. Of this 30 students the average age as of September 1, 1981, was 16.6 years. The mean grade point average of this class was 2.84 and the mean I.Q. of the class was 114 ranging from 88 to 136. The average Piaget score at the beginning of the course was 4.81. Of the 22 students measured, 10 were concrete and 12 were formal. The after Piagetian score was 5.33. The instructor participant of this particular class made the following statement concerning this section, "This class was dichotomous regarding the academic ability of its members. More than half of the students were very bright gregarious people. Although the less academically astute students increased in their interest and in an ability to interact as the school year progressed, they were sometimes overshadowed by the outgoing nature of the other students. Class discussions were always lively and profitable with a diversity of ideas being discussed and many students being involved in the interaction.

Section 22 was composed of 13 male and 12 female students making up a total of 25 students in all. The average age of these students was 16.6 years and their final mean grade point average was 2.93 on a scale of 4. The class I.Q. average was 114 ranging from 97 to 130. The mean before Piaget score was 4.52 and the after Piagetian score was 5.07. Using this information, 12 of the 17 students for which we have scores were concrete and 5 were formal at the beginning of the academic year. The instructor of this section made the following statement concerning the students. "This class was large at the beginning of the school year, but section transfers and semester drops resulted in about 1/3 reduction in size for the second semester which involved learning cycles 8, 10, 12, and 14. This class as a whole was easy going and moderately interested in the content of the course. There were 6 to 8 students in the class who would initiate discussion and ask questions on a regular basis. The remainder of the class could be drawn into discussion rather easily and the whole class interacted well in the laboratory. This class seemed to be relatively homogenous in its academic ability."

Section 25 was composed of 26 students, 11 males and 15 females. The average age of the students in this class was 16.5 years and their final mean grade point average was 2.44 on a scale of 4. The class mean I.Q. was 108 ranging from 77 to

143. The before Piagetian score was 4.38, the after Piagetian score was 4.53. At the beginning of the year 16 students were classified as concrete and 5 as formal. This student group, although not significantly different on any of the major characteristics with the exception of after Piaget score, nontheless had lower grade point average, I.Q., before and after Piagetian scores than any of the other groups in the research. The teacher participant made the following statement about these students, "This class was below normal in academic ability for a chemistry class. The social interaction among the members of the class was well developed, but often off the subject of the discussion at hand. There were several students in the class with high academic ability and high interest in the class work, but the class "personality" sometimes inhibited rapid progress through the content.

Gender Characteristics

Table 3-4 summarized statistical tests for differences between males and females on the five general characteristics measured for this research. As can be seen from this table, no significant differences are shown for any of these characteristics. For the purposes of this research, it will be assumed that the academic abilities of the sexes are equivalent.

TABLE 3-4: GENDER DIFFERENCES

SOURCE	DF	Mean Square	F	P
BPIAG				
Gender	1	0.86	1.07	0.30
Error	123	0.80		
APIAG				
Gender	1	1.50	2.39	0.12
Error	114	0.63		

GENDER	N	Mean	S.D.	T	P
GPA					
F	77	2.95	0.96	1.61	0.11
M	78	2.70	1.01		
TIQ					
F	72	112.4	13.0	-0.26	0.79
M	66	113.0	13.0		
GEFT					
F	69	12.3	0.5	-0.07	0.94
M	67	12.4	0.5		

CHAPTER FOUR

LC-2: PHYSICAL AND CHEMICAL CHANGE
A SECQUENCE EXPERIMENT

Experimental Design

This learning cycle was designed to teach the concept of Physical and Chemical change. Various activities were used to show students the types of change and the use of properties as evidence of change. Formally stated a chemical change was defined as "a change in matter that cannot be reversed by physical means." A physical change was defined as "a change in matter that can be reversed by physical means." A wide variety of changes were used as examples.

Although a more elegant definition of physical and chemical change would involve the idea of the formation of new compounds through the making and breaking of chemical bonds, this chapter was too early in the year for that. In fact, this concept was used in order to help the later development of the bonding concept.

LC-2 was designed as a sequence experiment (see also LC-12). Table 4-1 summarizes the experimental plan for the manipulation of the sequence variable. Six chemistry sections were involved. Each of the sections was assigned one of the six possible sequences of the three phases of the learning cycle (G = gathering the data, I = inventing the concept, and E = expanding the concept). Three equivalent forms (A, B, and C) of the CATs were developed for LC-2. The same form (A) was used as the pre and post test. The CATs were administered four times (CAT 1, 2, 3, 4); once as a pretest and once after each cycle of the learning cycle. The BAR attitude scale was not administered in this experiment.

Because tests were administered after each phase of the learning cycle, it was possible to artifically run necessity experiments. By using the post

TABLE 4-1

LC-2 Experimental Plan

Section	Phase 1	Phase 2	Phase 3
pre test Form A CAT 1	post phase 1 Form B CAT 2	post phase 2 Form C CAT 3	post test Form A CAT 4
11	E	G	I
14	G	E	I
16	I	G	E
21	E	I	G
22*	G	I	E
25	I	E	G

*control

phase one test (CAT 2), for example, one could study the necessity of the other two phases. Similarly by using the CAT 3 scores, one could study the result of omitting only one phase. Several interactions between necessity and sequence are also possible (See Table 4-2 for an example).

TABLE 4-2

LC-2 Side Experiments

Section	Post Cat	Symbols	Type of Experiment
11	2	E only	Necessity
	3	E G	Necessity X Sequence
14	2	G only	Necessity
	3	G E	Necessity
16	2	I only	Necessity
	3	I G	Necessity X Sequence
21	2	E only	Necessity
	3	E I	Necessity X Sequence
22	2	G only	Necessity
	3	G I	Necessity
25	2	I only	Necessity
	3	I E	Necessity

Description of Classroom Activities

Certain modifications in the presentation and/or function of specific phases of the learning cycle were necessitated by the variations of the sequence. Class discussions during the "Invention" (I) phase are based on data collected during the "Gathering Data" (G) phase. In situations where the I phase preceded the G phase in the sequence, the I phase became a lecture delivered by the teacher. (The invention lecture notes are included in Appendix 4B). These sequences were I, G, E; E, I, G;and I, E, G. For the two experiments that began with the "Expansion" (E) phase (E,I,G and E,G,I); plus the sequence G,E,I, terse definitions of physical and chemical change were given at the beginning of the E phase along with one example each of a chemical and a physical change. Aside from these necessary modifications, the material within LC-2 was presented as originally designed. Classroom materials used during LC-2 have been reproduced in Appendix 4A.

The specification of classroom activities by sequence and class days is summarized in the Table 4-3. Appropriate appendix page numbers corresponding to each activity are given in parentheses.

Post Investigation Discussion

After each learning cycle the principle investigator and the two chemistry teachers sat down and discussed their views of the success or failure of the learning cycle and the contrast between the experimental groups. The discussion began with a problem that one of the instructors noticed in themselves. This teacher was bothered by the lack of invention discussions with some of the classes. In one of the experimental classes this teacher had an invention discussion which preceded the gathering the data phase. As a consequence, there was no chance to discuss the actual laboratory after the "gathering data" phase although the students expressed a definite interest for a discussion. Because the discussion

TABLE 4-3

LC-2 Classroom Activities

Section / Day	E,G,I 11	G,E,I 14	I,G,E 16	E,I,G 21	G,I,E (Control) 22	I,E,G 25
1	E Demonstration (4A-6,4A-7)	Begin G (4A-2,4A-3, 4A-4)	I Lecture (4B-2)	E Demonstration (4A-6,4A-7)	Begin G (4A-2,4A-3, 4A-4)	I Lecture (4B-2)
2	Reading (4A-8,4A-9, 4A-10)	Finish G	Begin G (4A-2,4A-3, 4A-4)	Reading (4A-8,4A-9, 4A-10)	Finish G	E Demonstration (4A-6,4A-7)
3	Begin G (4A-2,4A-3, 4A-4)	E Demonstration (4A-6,4A-7)	Finish G	I Lecture (4B-2)	Idea Question-Small group (4A-5)	Reading (4A-8,4A-9, 4A-10)
4	Finish G	Reading (4A-8,4A-9, 4A-10_	E Demonstration (4A-6,4A-7)	Begin G (4A-2,4A-3, 4A-4)	I Discussion (4B-2)*	Begin G (4A-2,4A-3, 4A-4)
5	Idea Questions - Small group discussion (4A-5)	Idea Questions - Small group discussion (4A-5)	Reading (4A-8,4A-9, 4A-10)	Finish G	E Demonstration (4A-6,4A-7)	Finish G
6	I Discussion (4B-2)*	I Discussion (4B-2)*	------	------	Reading (4A-8,4A-9, 4A-10_	------

* The ideas developed in class discussion parallel the ideas presented by the invention lecture.

preceded this phase, the teacher felt that the students were frustrated. The teacher felt this way even though the invention discussion covered the same information prior to the "gathering the data" as did the control groups which had the discussion after the "gathering the data" phase. "We listed 8 chemical changes all of which they saw in the lab, but it didn't explain it to them. They just didn't connect the two," according to the teacher. In other words, the students did not see that the material covered in the invention, which preceded the "gathering the data" phase, was demonstrated by the laboratory itself. As one of the other teachers said, "It was like doing three separate activities. There was a lecture; there was an expansion of the idea; there was a laboratory. It was phenomenal how there was no connection made."

When asked what kind of evidence they saw that indicated that there was no connection made, the teachers gave a couple of examples. One of these examples was concerned with the reaction of calcium with water to produce insoluble calcium hydroxide. The students didn't realize that the residue of calcium hydroxide was there as a result of a chemical change and that the formation of an insoluble product was one of the signs of a chemical reaction that was discussed in the previous invention discussion. Not only did they not see that there was a chemical change, but in the case of calcium reacting they didn't even see that the resulting calcium hydroxide was a different material. Many asked the reason why the beaker was so hard to clean out. The salt solution beaker in another part of the experiment was easy to clan out, but the calcium reaction beakers were difficult to clean. In other words, the students who had the invention discussion prior to the experiment did not make the connection that the material did not interact with the water and, therefore, must be different than the material that they started with since it did react with water.

The teachers also identified a major misconception associated with the dissolving process. Many students thought that calcium, a material which reacts with water, did not react with water but rather dissolved in water. In other words, calcium forms a solution in water much as sugar or salt does. When asked if some of the classes were more bothered by this misconception than others, one of the teachers said that it was seen more in the IGE sequence when the invention was first than, in the other two sequences which had a laboratory activity first. "It wasn't as obvious there", said one of the teachers. "Actually when you have a GE or EG sequence before the invention it's just one big laboratory activity. You don't really notice the difference between those two sequences." The other teacher, however said that he didn't notice any big difference. "In fact," he said, "I had the control group, the GIE, and there were also some problems associated with this water solution of calcium idea." There was, however, what he felt was a big difference between the control group and the other sequences. "I noticed in the control group that when we got to the expansion phase things seemed to be pretty well all ducks in a row. I put calcium in water for the expansion and found that they used similiar observations that they had made in the calcium laboratory before. Now that in and of itself isn't too great a deal because we used calcium in the laboratory, but when I put aluminum and hydrochloric acid together in our demonstration, there was a chemical change and the students utilized observations of the same type that they had used in the calcium laboratory. They seemed to have a much clearer idea of what a chemical change was by the time we got to the expansion."

In further commenting on the invention lecture coming before any laboratory activities, either of the "gathering the data" phase or the "expansion" phase, one of the instructors indicated that the invention lecture was a very passive experience for the students. "They just wrote every thing down and it stayed there right on paper. It didn't seem to go into their heads at all. There was no connection when we got to the other phases. The investigation phase, that was fine, it was an entity. The expansion phase, fine, that was an entity also. The gathering the data phase, that was an entity. Any tying together that was there, and there was some, was done in review when we finished going through all of this. It wasn't as a result of the interaction during the learning cycle. It was just kind of pieced together after the fact." This instructor furthermore used some of the information from the case studies indicating that the students who had gotten the invention discussion prior to the experiments seemed to be trying to use textbook definitions to answer questions about whether changes were physical or chemical in nature. Although the definition of chemical and physical changes at this point in the year is given in terms of the reversability or nonreversability of phenomena, the students didn't seem to spontaneously use those definitions in order to try to explain what kinds of specific reactions were occurring. In other words, when asked what a physical or chemical change is in the abstract, students will give you a definition of physical and chemical changes in terms of reversability. But when they are trying to determine the specific nature of a particular change, they often referred to other sorts of alternate conceptions. In the readings there was an example of a chemical change involving the hardening of an egg when it's heated. When asked whether it was a physical or a chemical change, students seemed to get the idea that the answer was based on information that they got from some other source. For example, several students said that there had to be two or more substances for a chemical reaction to occur. Since there was only one substance in the hardening of an egg (egg white was only one substance according to them), they thought this reaction couldn't be a chemical change. The other teacher indicated that after the discussion of a hardening of an egg, the students were asked for a definition of a physical change. The students replied that it was a change that could be reversed by physical means. When the teacher then asked how you would reverse the salt water dissolving by physical means, the students answered "by driving off the water." However, when the teacher asked about the egg, the students were a little bit uncomfortable.

They tried to bring in the idea that temperature was a substance; that it was something that you could put into or take out of a substance. They thought there must be some way to physically remove the heat by changing the temperature. Even with the case of the physical change, many students seemed to indicate that the salt water mixture was depended upon changing the temperature of the system. The students didn't see that the water was the critical material in this particular case. That you are adding water and then taking the water away. One of the teachers brought up the point that the control group was the only one of the groups that really displayed an understanding on the unit examination and expressed the idea that when you get a chemical change you wind up with a different substance which could not be changed back to the original substance without undergoing something other than physical change.

There was some discussion at this point, that the CATs might have overemphasised the reversability phenomenon to the extent that other aspects of physical and chemical change were ignored. One of the teachers, in agreeing with this, said that he didn't believe that many of the students had a good idea of what we were asking on the examinations, and as a consequence, some students did not focus on physical and chemical phenomenon. It was also discussed that the systems that were used on the CATs were not as familiar to the students as the developers of the CATs thought they would be.

When asked whether the students seemed confused or upset by the different sequences used in the experiment, the teachers indicated that they didn't notice very much confusion. Their explanation was that students have a fairly high tolerance for unintelligible classroom activities. "Students pretty much take the stuff as it comes to them without really getting too upset about whether it fits in with materials that come before or after it." One teacher's opinion was that the learning cycle approach forces students to put the various parts of a lesson together because of the design of the activities.

From the information developed from classes which had the invention discussion first, it seemed that the students had assimilated the information given in the invention lecture. This was evidenced by the fact that the students were able to give accurate definitions as a result of having been exposed to them. However, there was little evidence that the students could apply the information to specific examples.

Both teachers remarked that they had always thought that the distinction between physical and chemical change was a pretty simple concept, one that most high school teachers brush over quickly. Yet, it was apparent that there is among a few students, major misconceptions about change that seem prevalent even after instruction is finished.

Case Studies

During the activities of LC-2, one student was randomly chosen from each of the six classes to serve as a case study. These students were not considered to be necessarily representative of their class. However, it was felt that insights into these students learning processes and attitudes might provide insights into the other data collected and help to explain the learning (or lack of learning) which takes place during science lessons. Each case study was interviewed before the lesson began and after each of the phases of the learning cycle. The interviews were conducted by the principle investigator and the two chemistry teachers who each interviewed students in the other teacher's classes. Following are discussion of the six case studies.

Case Study 2. Case Study 2 was in class 11 and went through the sequence EGI. The E portion consisted of a classroom demonstration followed by some readings. The G was the normal "gathering data" phase. This was carried on for 2 days. This was followed by some idea question in small group discussions. The I phase was a classroom discussion. The CAT was given as a pre-test and then following each phase. As can be seen from Table 4-4, CS-2 received about equal scores on the first two CAT tests (pre-test and post E phase test). This was followed by a slight dip in the post G phase CAT score. A rapid increase followed in the part I phase, reflected in CAT 4. This pattern seems to suggest that this subject was making limited sense out of the experiences associated with the laboratory and demonstrations and readings until the classroom discussion was held, which in this particular sequence was done right at the end of the series of lessons. The case study was interviewed 4 times during the series of lessons. Once before the lessons began and then after each of the phases. She was also observed during class work along with other members of her class while the lessons were taking place. Since the lesson was on physical and chemical change much of the discussion with the case study was concerned with her idea of what the nature of chemical and physical changes were.

The interviewer summarized the pre-lesson discussion as follows: "CS-2 doesn't really know what I'm driving at concerning change. She doesn't really remember anything from junior high school and doesn't feel she has had enough chemistry to give specific examples of change. She mixes physical and chemical change without classification. During this discussion she volunteered that she is comfortable with the course, likes the teachers, and feels the discussions that they have in class help her learn the material very much. Her favorite course is the Anatomy/Physiology course that she took. She likes Biology very much. Her real love is French, but she will study physiology in college and go into medicine."

After the exploration phase, CS-2 had her second discussion with the interviewer. "Because of our previous discussion she said she was trying to find out about physical and chemical changes in the laboratory. She said she mixed aluminum and hydrochloric acid and looked at the reaction to try to determine whether it was physical or chemical. She concluded it was a chemical change because it can't be reversed by physical means. She also felt, however, that changes from liquid to solid also are chemical changes because they can't be reversed. She felt that some of the quiz questions were confusing. For example, starting a gasoline engine. She felt sure about grating cheese. She felt that since it was reversible it must be a physical change. But shredding paper was non-reversible, she said, and felt it must be a chemical change, although she didn't feel sure about that."

The third conversation with CS-2 discussed the gathering the data phase laboratory activity. She outlined the procedures that she went through in order to investigate the interaction of calcium metal with water and compared that with salt being swirled and mixed in water. "She concluded that the salt weighed less (4.42 grams - 4.39 grams = -.03 grams) after having dissolved it and then evaporated the water. The calcium, however also became more weighty by around .90 grams. The weight differences, however didn't seem to be significant to her and she didn't bring up the idea of physical versus chemical change spontaneously. I finally had to and asked her directly. Calcium definitely was chemical, she said, because it can't be reversed. It totally changed form and color and let off a gas. The salt, however, would also be a chemical change, she guessed, because she didn't know how you would reverse the dissolving process, although, in fact, she did reverse it by evaporating the water in the experiment. When asked if her ideas about physical and chemical change had changed as a result of the laboratory activity she said no."

The final discussion with CS-2 took place after the end of the invention discussion. In this particular case, she said, that the salt system was a solution and that it was, therefore, a physical change. Evidence of this was that when the water evaportated it was still salt although not in the crystalline form. All we added, she said, was salt and water. There wasn't any weight change, although after the third discussion she indicated there was a weight change. The calcium system was a solution also, she said, but this was a chemical change because it let off gas, looked different, and there was a weight change.

TABLE 4-4

CASE STUDY PROFILE

Student	2			
Sex	F			
Class	11			
Grade Level	11th			
Birthday	10-13-65			
I.Q.	114			
GEFT[1]	13	(Quartile ____)		
VH[2]	4			
FR[3]	3	5		
CC[4]	5	5		
Grades[5]	A	A	B	B

Variable Sequence

Group EGI

LC 2 test scores (unadjusted)

CAT 1	57 %
CAT 2	57 %
CAT 3	38 %
CAT 4	76 %

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1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

The subject indicated that she first thought about physical and chemical changes after Learning Cycle 1 during a class discussion. She still felt she was not sure when something is a physical or chemical change. She's more sure today, however, after the class discussion.

The subject's behavior in class seems normal in compared with other students. She worked diligently on the note taking during class discussion, although she was fairly passive through most of these discussions. She also was involved with passing a note occasionally and exhibited other non-lesson related behaviors. In laboratory she worked through the material in a fairly straight forward fashion although she also spent some time socializing on non-lesson behaviors with her laboratory partner and others in the room.

Case Study 29. This student went through the sequence GEI. This particular sequence was similar to the sequence of section 11 with the exception that the order of the gathering the data and the exploration phase were reversed. The critical element of having the invention discussion last, however, was the same in both of these groups. CS-29's grade on CAT 2 was lower than the grades on CATS 1, 3, and 4 (See table 4-5). Since these tests were, high to begin with (as is true of the students on this particular unit), one is left with the conclusion that either the quizzes themselves were too easy to get any discrimination among the students, or that the material was already fairly familiar to the students through past experience. In the pre-investigation interview, the student talked about physical change as a change of state, that is solid, liquid, and gas. He mentioned, however, that one might mix two chemicals together and get something else. This would be a chemical change. During the expansion demonstration, the subject wrote definitions and moved to the front of the class in order to see better. He took extensive notes and seemed very attentive, although he didn't become involved in the class discussion.

During the post-expansion interview, the student was asked for his impressions

TABLE 4-5

CASE STUDY PROFILE

Student	29				Variable	Sequence
Sex	M				Group	GEI
Class	14				LC 2	test scores (unadjusted)
Grade Level	11th					
Birthday	06-12-65				CAT 1	62 %
I.Q.	114				CAT 2	38 %
GEFT[1]	18	(Quartile 4)			CAT 3	57 %
VH[2]	4				CAT 4	67 %
FR[3]	6	6				
CC[4]	5	5				
Grades[5]	B	B	C	B		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

of the demonstration. He felt that the definitions didn't give enough information to help him decide between physical and chemical changes. Since the invention discussion was not yet held in this sequence this seems to be a perfectly natural reaction. CS-29 was asked whether his predictions of chemical and physical change were supported by the discussion that was held after the demonstration. He said that he correctly predicted each, but was tentative in his predictions prior to being told. He based his predictions on observed changes in the systems. He didn't feel that his ideas about chemical and physical change have been altered significantly as a result of the work done so far.

After the "gathering the data" phase, the subject was asked if doing the experiments with salt and calcium had changed his idea about chemical and physical change. He felt that the experience had not changed his ideas. Upon questioning he said that calcium and sodium chloride changed chemically when water was added, but that the heating process was physical in both systems. He complained gently about the frequency of the CAT testing. After the invention discussion, the subject listed percent weight change data after group discussions of idea questions. The subject initially thought that the sodium chloride in water was a physical change but his group talked him out of it, because they said it didn't look the same after heating.

Case Study 48. CS-48 was a very good student as is reflected in his overall GPA (See table 4-6). His CAT scores increased from the pre-test score but remained almost level throughout the remainder of the exercise. This particular student underwent the sequence IGE. The investigation discussion, because it began the lesson, took the form of a lecture. In observing the work habits of this particular student in the laboratory, the class observer was very impressed with how well the case study and his partner worked together. Without hurrying they seemed to be able to get way ahead of the rest of the class. If there's a leader however it was assumed that it was the case study's partner that was doing the leading in the laboratory work. In any event, both of their observations were very systematically done in great detail. These students followed instructions, but didn't seem to really think about what was happening until a question or a calculation required that they think. Otherwise they seemed to automatically go their way through the exercises.

During subsequent laboratory activities these two students seemed to slow down considerably as a result of their very detailed observing and very thorough manipulation of the equipment. During the classroom discussion of the demonstration of a discussion of the calcium and water interaction, a student asked the teacher if it was a physical change when water evaportated and they had calcium as a result. The instructor said that if we had calcium when it evaporated it would be a physical change.

The students do not seem to be using the weight data, although it's available. The teacher was having trouble convincing them that calcium plus water is a chemical change. They were not focusing in on the weight data. Some confusion and misconception seemed to result. The major misconception that seemed to come out of this was that dissolving is equivalent to a reaction. The teacher finally had to tell the students that calcium plus water was a chemical reaction. It's hard to say whether this phenomenon was a result of having the lecture come first in the sequence. Because the physical and chemical change definitions were set up prior to any experience, it might be hypothesized that this limited the student's ability to deal with the situation in the exploration which came later. CS-48 did not show up for his pre-investigation interview. The observer felt that the case study was attentive to the instruction and took down notes and definitions during the classroom invention lecture. His body language indicated that he was involved but he did not participate in the discussion. The entire class was attentive and many responded verbally to the questions that were asked. After the invention discussion, the CS-48 was interviewed and gave as a definition for a

TABLE 4-6

CASE STUDY PROFILE

Student	48		Variable	Sequence
Sex	M		Group	IGE
Class	16		LC 2	test scores (unadjusted)
Grade Level	12th			
Birthday	11-10-64		CAT 1	43 %
I.Q.	123		CAT 2	62 %
GEFT[1]	10	(Quartile 2)	CAT 3	62 %
VH[2]	5		CAT 4	67 %
FR[3]	6	6		
CC[4]	4	5		
Grades[5]	A	A	A	A

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

physical change that it was reversible process and for a chemical change that it was an irreversible process. CS-48 seemed more certain about physical than chemical changes and gave examples of physical but couldn't give an example of a chemical change. Again this might have been the result of having the invention discussion in the absence of any concrete examples. The subject used water freezing and melting as a physical example. He said he had known about physical changes before but not about chemical changes.

Case Study 67. CS-67 went through the sequence EIG. There is some reason to suspect that in this particular sequence, which has the gathering the data phase and the exploration phase activities reversed, the "expansion of the idea" phase may serve as an introduction to the topic. If this hypothesis is true, then this order of activities might theoretically be very similar to the normal learning cycle sequence. CS-67 had fairly poor grades throughout the semester (See table 4-7), although during the time this learning cycle was carried out his grades were more adequate. The CAT scores that he had on this particular unit started lower than most students, then went higher after the E phase, then lower again after the I phase, and finally higher again after the G phase, the last phase in this particular sequence. During the pre-investigation discussion CS-67 indicated that the questions were not clear to him on the pre-test. The subject indicated that he liked chemistry and his interests lie toward science.

After the expansion phase demonstration and readings, the subject defined a chemical change as a change that cannot be reversed by simple environmental means, and a physical change one that can be reversed by simple environmental means. As an example of a chemical change, he used $FeCl_3$ in water. The reason for this is that the $FeCl_3$ combined with the water to make a solution. As an example of a physical change, he used boiling water as an example. He indicated this process could be reversed by taking the heat away. At this point CS-67 changed his mind and said that the $FeCl_3$ plus water was, in fact, a physical change and he couldn't

TABLE 4-7

CASE STUDY PROFILE

Student	67				Variable	Sequence
Sex	M				Group	EIG
Class	21				LC 2	test scores (unadjusted)
Grade Level	12th					
Birthday	07-27-64				CAT 1	29 %
I.Q.	103				CAT 2	57 %
GEFT[1]	18	(Quartile 4)			CAT 3	38 %
VH[2]	4				CAT 4	71 %
FR[3]	3	3				
CC[4]	5	5				
Grades[5]	B	D	F	D		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

remember an example of a chemical change. Then he said that hydrochloric acid plus iron produced a gas. "The iron was eaten away by an acid." The discussion associated with the demonstration and reading, he said, helped him in answering the question. He also felt that the interview itself helped point out some of his mistakes, although there was no attempt during the interviews to do this.

After the invention discussion the subject indicated that the differences between chemical and physical change were pointed out and that, therefore he had a much better idea of the difference. When he was asked to discuss putting sodium chloride in water he said that the large molecules went to the bottom and the small one raised to the surface. "How would you know", he was asked, "if it dissolved?" He said to say that it would be heated, and then you could see in the bottom whether it dissolved or not.

After the G phase activity was finished, the final interview with CS-67 took place. He was asked whether salt in water was physical or chemical. It was physical, he said, "because you could reverse it back." Calcium in water was also physical because it could also be reversed. The student commented that the weight was more after the water was added and it produced a gas, "and when you added water back to the beaker the calcium was not in the same form. It was more powdery than it was before." He was asked if he applied what his teacher had said to him about physical and chemical change during the laboratory. He said that he really didn't think about it. It's obvious this student still has a lot of confusion about physical and chemical changes.

The lessons in this particular sequence began with a very brief definition of physical and chemical changes. There didn't seem to be very many questions after these definitions were developed. This is not surprising in view of the nature of the lecture. The students were passive during the demonstration but seemed to be attentive. They followed the teacher's instructions and wrote down information about their observations during the demonstration. When the instructor asked if the interaction between calcium and water was a chemical or physical change, after having tested it with litmus paper (red changing to blue), a student asked if it was possible for it to be both. At first this student asserted that it could be both. Another demonstration involving copper sulphate solution and ammonia showed a color change. A student asked if the color change was homogenous. The teacher passed the reaction vessel around and then asked if the change was a physical or chemical change. One student thought that it was a chemical change because of the color change. Some students noticed that there are some crystals on the bottom of the beaker. The instructor asked if litmus test was evidence of a chemical change. Both yes and no answers seemed to result from this. One student said that we had more acid as a result of the reaction and was, therefore, a chemical change. All during this demonstration there were evidences of minor misconceptions not necessarily having anything to do with physical and chemical change. There were some misconceptions on the use of evidence. The class was quiet but attentive and responded well to the instructor's questions. The instructor tried to deal with misconceptions using logical arguments. It was difficult to tell how effective the arguments were.

Case Study 99. CS-99 was a fairly bright student, but was subject to classroom misbehavior. His scores on the CAT examination for this sequence were spotty and didn't seem to change very much from beginning to end (See table 4-8). This particular sequence was the normal or control sequence for this experiment (GIE). The pre-investigation discussion with CS-99 indicated that he had a good, perhaps memorized, if imprecise definition of chemical and physical change from an 8th grade class he had previously taken. He did not however recognize the CAT examination pre-test as asking for chemical and physical changes. Examples of physical and chemical changes were not readily available to him.

TABLE 4-8

CASE STUDY PROFILE

Student	99				Variable	Sequence
Sex	M				Group	GIE Control
Class	22				LC 2	test scores (unadjusted)
Grade Level	11th					
Birthday	01-19-65				CAT 1	62 %
I.Q.	125				CAT 2	48 %
GEFT[1]	11	(Quartile 2)			CAT 3	43 %
VH[2]	4				CAT 4	57 %
FR[3]	5	--				
CC[4]	4	6				
Grades[5]	B	B	B	B		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

After the "gathering the data" phase the second interview with CS-99 took place. He indicated that the salt was heavier after the water was driven off of it than it was before. Actually the amount of increase was .06 grams. The subject had no explanation for why it was heavier, but he did wonder about it. He said it was heavier and "I was surprised but I didn't know why it should be." This seems to be a fairly common misconception about the nature of weight changes. The amount of weight change involved here is infinitesimal in comparison with the weights that were originally used. As a consequence one would hope that the student would see this small a weight as being insignificant and, therefore, the result of experimental error. However, many students don't interpret the data in this way. Any weight that's not either so terribly small that it's obviously insignificant or else is not exactly the same as the original weight indicated to many students that there was a real weight change.

CS-99 didn't remember very much about the calcium plus water reaction. He said that he had thought about it a little but mostly he was concerned with getting procedures done. "Otherwise you don't get done." He spent much of his laboratory time talking with his partner, and treated the activity as something which had to be done. "I suppose I will end up learning something in spite of myself. Can't spend as much time of experiments as you'd like to, otherwise you won't get finished."

CS-99 is a junior who's going to college. He wants to do business or PR work. History is his favorite subject and he's taking chemistry because he was advised to do so. His main interest seems to be track.

After the invention phase discussion the case study talked about physical and chemical change. He defined physical change as a change that can be reversed and chemical change as a change that cannot be reversed. He thinks that he was pretty much right about what he had said in earlier interviews. The interviewer asked what he meant by reverse. He said putting substances back in their original form.

The salt and water example was identified as a physical change because "when you boil the water what was left was salt again. It's the same weight basically assuming that." The calcium experiment, however, was a chemical change because once it was mixed with water it emitted gas. "The stuff on the side was hard to get off. It put out heat." CS-99 gave two examples of physical change, an ice cube freezing and melting, a crayola and putting it back together. He, however, was unable to come up with a specific example of a chemical change. "Just putting two chemicals together, coming up with a third one," he said.

After the E phase, the case study was asked to describe the ammonia plus copper sulphate system and the hydrochloric acid plus aluminum system. He also discussed the reading on boiling eggs, describing the hardening of the white and yolk as a physical change. When asked why, he said, "there's not a whole lot to it except boiling, altering its present state." This was an interesting result in view of a discussion which took place later. The interviewer asked, "What do you mean by physical change or by physical means?" CS-99 said, "You don't have a change. You can put it back together again. A person can do it." "For example," the interviewer asked? CS-99 said, "Well, you could tear a newspaper and you could tape it back together again." "What about boiling an egg?", the interviewer asked. The subject said, "I'm sure there must be a way, but I don't know what way would be to change it back." His definition of a chemical change was, "you add two substances to form a third substance." When asked if he thought his ideas changed from the beginning to the end of the lesson, he said he thought he had the same basic ideas, made more specific by the activities of the investigation. He also said that on the three versions of the quiz that he answered everything pretty much the same except for those that he didn't know anything about, for example, drying apricots.

The observer who watched the case study and his partner in laboratory remarked that they seemed unusually lackadaisical. If they were thinking about what they were doing, there was no evidence from these observations. Other groups seemed to be more attentive and intense in their observations than this group. During class discussions the case study was unusually inattentive. During critical parts of the discussion he was not paying attention, usually talking with a neighbor or staring out into space.

One of the interesting observations made by the observer during this and other laboratories was that during laboratory activities students are attentive but seemed to just march through the instructions without paying too much attention to the results and what they might mean. For the most part students follow instructions in the laboratory. They seem to expect to find the salt left over after heating and calcium left also after heating. This expectation is confirmed when they find material left in the calcium beaker. Although they find the calcium beaker hard to clean, they do not draw the conclusion that the residue could not be the same as the original calcium because the water did not have the same reaction with it that the original calcium did. These sorts of observations which are obvious to a trained scientist are just not obvious to students, without having their attention focused upon them.

Case Study 113. This case study went through the sequence IEG. Since the invention discussion began this particular lesson, it is thought to be similar to the IGE sequence of Section 16. This particular student seemed to be an extremely poor one as evidenced by his dismal grade point average (See table 4-9). The CAT test began very low and improved until they became relatively respectable by the end of the session. His CAT 2 and 3 scores were about the same and then finally after the "gathering the data" activity they went to their highest level. Unlike many of the other students, this particular subject didn't appear to know very much at all about physical or chemical changes, at least initially. The observer who watched this case study during classroom sessions seemed to indicate that the student was

TABLE 4-9

CASE STUDY PROFILE

Student	113			Variable	Sequence
Sex	M			Group	IEG
Class	25			LC 2	test scores (unadjusted)
Grade Level	11th				
Birthday	01-27-65			CAT 1	14 %
I.Q.	97			CAT 2	43 %
GEFT[1]	9	(Quartile 1)		CAT 3	48 %
VH[2]	4			CAT 4	62 %
FR[3]	4	4			
CC[4]	4	4			
Grades[5]	F	C	F	F	

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1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

unusually passive, although not necessarily inattentive, to the classroom activities.

Since the initial activity of this lesson was an invention discussion which took the form of a lecture, most of the students were reduced to taking notes and asking questions. Several of the students indicated that they were thinking about what was being said. The attention of the class, however, slacked off about halfway through the lecture. The students were given ample opportunity to ask questions but asked very few. This particular invention discussion was followed by a demonstration and then some readings. This meant that there was an unusually long period of time where the students were not involved directly with laboratory activities, but instead were in a fairly passive state. After the exploration activities there was some confusion as to what was needed to prove whether a change was chemical or physical. The class was very involved, although the case study himself did not seem that interested.

The pre-investigation interview occurred after the student took the pretest. He could, however, not remember very much about the test. When asked about a physical change, he defined it in terms of the appearance of the material. Chemical change involved "a reaction, stirring it up, turning a different color." After the invention discussion CS-113 indicated that a chemical change is one that cannot be reversed. "Gasoline in an engine for example, shredding cheese cannot be reversed," he said, "and therefore must be a chemical change. Physical changes can be reversed. Burning candles, for example, are physical changes because they can be re-melted and remodeled."

Because the student did not attend any of the scheduled interviews until the final appointment, the next interview took place after the end of the activities. Sodium chloride in water was described as "nothing happened. The mixture conducted electricity but was not a solution because there was no change." When asked what a chemical change was, CS-113 said he didn't remember. He described the calcium in water system as a gas producer. This change was described as physical. When he asked why it was physical, he said, "you could see it happen."

Achievement Analysis (Sequence)

As was mentioned in Chapter 2 this sequence experiment utilized three forms of the Concept Achievement Test (CAT) labelled A, B, and C (See Appendix 4C). These tests were assumed to be equivalent in order to make some of the judgments necessary in the statistical analysis which will follow. In order to justify the equivalence of the three forms of the test they were cross-validated as described in Chapter 2. The findings of the cross-validation indicated no evidence that the forms were different from each other and as a consequence they will be treated as equivalent in the analysis that follows.

The percentage scores for each of the CAT tests were determined and means and standard deviations can be found in Table 4-10. This table has the mean and standard deviation of each of the four CAT scores, sub-divided by each of the six classes involved in this sequence experiment. These scores are further subdivided as to mean scores of students who were judged concrete versus those judged formal operational on the basis of the Science Reasoning Tasks.

The analysis of variance for each of the CAT's (1 - 4) by developmental level versus class can be found in Table 4-11. The summary of the significance tests between means using the Newman Keuls can be found in Table 4-12. As can be seen from that analysis there is a difference between classes on CAT 1 which was the pre-test. This is unexpected since there was no reason to think that any of the classes would show more knowledge of the material at the pre-test level than students in other classes. Studying the means for CAT 1 there appears to be an inflated value for concrete students in Section 22, which was the control group for this sequence experiment. For formal operational students there seemed to be inflated values for Section 14 and unusually low values for Section 11. Several

TABLE 4-10: LC-2: PHYSICAL AND CHEMICAL CHANGE

Summary of Mean Scores

Class Means

		11	14	16	21	22	25
CAT 1	concrete	46.5	48.8	39.4	48.4	58.4	51.1
	formal	44.0	63.3	48.4	52.0	55.6	60.0
CAT 2	concrete	53.0	47.1	41.5	49.8	56.1	52.8
	formal	62.6	56.4	61.3	57.7	58.9	67.2
CAT 3	concrete	39.2	38.1	42.9	44.5	46.1	42.1
	formal	48.3	56.1	59.7	56.2	37.5	56.1
CAT 4	concrete	66.2	60.6	51.6	57.5	53.9	50.4
	formal	63.6	66.7	71.8	70.9	56.9	71.2

TABLE 4-11: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANOVA for CAT 1-4, Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P
CAT 1: Pre Test				
Developmental Level	1	839	3.73	0.06 *
Class	5	722	3.21	0.009 *
Class X Level	5	239	1.06	0.38
Error	121	225		
CAT 2: Post Phase I				
Developmental Level	1	3536	23.25	0.0001*
Class	5	271	1.78	0.12
Class X Level	5	192	1.26	0.28
Error	122	152		
CAT 3: Post Phase II				
Developmental Level	1	3143	16.18	0.0001*
Class	5	295	1.52	0.18
Class X Level	5	485	2.50	0.03 *
Error	119	194		
CAT 4: Post Phase III				
Developmental Level	1	3130	15.56	0.0001*
Class	5	247	1.23	0.30
Class X Level	5	472	2.35	0.04 *
Error	117	201		

* Statistically significant

TABLE 4-12: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANOVA for CAT 1-4, Developmental Level vs. Class

Summary of Significance Tests Between Means Using

Newman-Keuls at $\alpha = .10$.

CAT 1: formal > concrete

Class 22, 14, 25 > Class 16 11

CAT 2: formal > concrete

CAT 3: formal > concrete

Class 14, 15, 21, 25 formal > Class 14, 16, 21, 25 concrete

Class 16, 14, 22 formal > Class 25, 21 concrete

CAT 4: formal > concrete

Class 16, 25, 21 formal > Class 16, 25, 21 concrete

Class 11 concrete > Class 25, 16 concrete factors might be operating here which might need to be taken into account.

First of all, this particular content area, physical and chemical change, was taught fairly near the beginning of the course and might be considered to be general knowledge from past courses for at least some of the students. Because of this factor it might be the case that the pre-test scores were very close to being the maximum scores that some of the students could obtain. There was also some evidence that the examination itself was confusing to the students and as a consequence they did not see that the test questions were asking about the concept of physical and chemical change per se.

Another possible interpretation however is that some of the classes just had more knowledge of the concept at the pre-test level than the other classes did. One of the possible ways of dealing with this is to do an analysis of covariance using the pre-test score as a covariant. The difficulty with this is that classes which have high pre-test scores may not have very much room to gain, since the post-test scores might have a maximum practical score. As a consequence, although there is more knowledge at the pre-test level, there's also less knowledge to gain, and the covariant will artifically show this class to have a lower post-test score in comparison with other groups. Nevertheless, an analysis of covariance was carried out using the pre-test as a covariant and Tables 4-13 and 4-14 summarize the information of that analysis.

In studying the results of the analysis of variance for each of the four CAT tests (Table 4-11) it can be seen that the formal operational students outscored the concrete operational students on every CAT test and every phase of the sequence. With the exception of the pre-test, there is no overall class main effect for any of the CAT's at any of the post-phase conditions. This is true of CAT 2 in spite of the fact that the invention phase is first in section 16 and 25. If any of the classes had a chance to show a difference on the CAT 2 it would be these two classes since they were the only classes which would have been introduced to the concept in any other form.

The CAT 3 showed an interaction effect between class and developmental level. Part of this effect is explained as being the result of the formal students outscoring the concrete students in Section 14, 16, 21, and 25. Part of the effect is also explained by formal students in Sections 16, 14, 25 and 21 outscoring the formal students in section 22. This is surprising since section 22 is the control group. There are no differences between the concrete students of the various classes.

There was also an interaction effect in CAT 4 (post-test) which would show the effect of the overall sequence on the final test score. In this case the interaction shows that in three classes (16, 25, and 21) the formal students did better than the concrete students. This analysis also shows that concrete students in class 11 outscored concrete students in classes 25 and 26. Since classes 25 and 16 are the two sequences where the I phase is first and class 11 is one where the I phase is last, a tentative conclusion might be that concrete students learn better when activities preceed concept discussion. There are no differences between the formal students of the various classes.

The analysis of covariance (Tables 4-13 and 4-14) shows differences between classes in CAT 3 and CAT 4. In CAT 3 classes 16, 25, and 21 all score better than the control group, section 22. This analysis seems to group the six sections into four groups. The IG sequence has the highest score. The EI and 1E sequences are next. These are followed by EG and GE sequences. Finally and unaccountably comes the GI sequence.

From CAT 4 it can be shown that classes 11, 14, 16 and 21 all have larger scores than class 22. Of course, as was mentioned earlier, this analysis of covariance data can be explained in terms that the control group itself was the one that had the highest pre-test score and was most affected by using the pretest as a covariant.

TABLE 4-13: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANCOVA for CAT 1-4, Developmental Level is Class Using
Pretest (CAT 1) as Covariate

Source of Variation	DF	Mean Square	F	P
CAT 2:				
CAT 1	1	1745	12.24	0.0007
Developmental Level	1	2263	15.87	0.0001
Class	5	246	1.72	0.13*
Class X Level	5	161	1.13	0.35
Error	115	143		
CAT 3:				
CAT 1	1	3049	17.19	0.0001
Developmental Level	1	1668	9.40	0.003*
Class	5	482	2.72	0.02*
Class X Level	5	284	1.60	0.16
Error	111	177		
CAT 4:				
CAT 1	1	2909	17.36	0.0001
Developmental Level	1	1594	9.52	0.003*
Class	5	361	2.15	0.06*
Class X Level	5	298	1.78	0.12
Error	111	168		

*Statistically Significant

TABLE 4-14: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANCOVA for CAT 1-4, by Class Using Pretest as Covariate
Summary of Significance Tests between Means Using Newman-Keuls (= .10)

CAT 3: Class 16 > Class 22, Class 11, Class 14
Class 21 > Class 22
Class 25 > Class 22

CAT 4: Class 11, Class 14, Class 16, Class 21 > Class 22

Composite Classes. There was some discussion among the project staff that if the sequence of activities influences a lesson, some of the segments of the learning cycle may change role as a result of changing sequence. The most common phases associated with this discussion was the possible interchanging of the "gathering the data" phase and the"expansion"phase. The argument was that an expansion phase which was manipulated to be the first phase of a lesson, might play the role of the "gathering the data" phase as a result. Also, that phases or sequences where both E and G are clustered together might be treated by students as one long "gathering the data" phase. Because of this, it was felt that there might not be any differences between an EIG and a GIE sequence, or between the EGI and GEI sequence.

The data studied up to now does not give a very clear picture to the answer to this hypothesis. As a consequence, it was decided to study composite classes which would gather together classes where the G and E phase served a similar function. It was felt that useful composite classes to use would be those where the invention stage was in the same position. As a consequence classes 11 and 14 where the I phase was last, 16 and 25 where the I phase was first, and 21 and 22 where the I phase was second were clustered together in composite classes and analyses were done on them. Table 4-15 contains the summary of mean scores for the composite classes outlined above. Tables 4-16 and 4-17 contain the analysis of variance for CAT 1 through 4 by developmental level and composite classes and also contains the Newman Keuls significant test between the means. Tables 4-18 and 4-19 contained analysis of covariance using the pre-test as a covariant and the summary of significance between the least square means using the Newman Keuls.

In studying the analysis of variance tables and Newman Keuls summaries on Tables 4-16 and 4-17, it can be seen that once again the developmental level main effect has shown that formal students score higher on the CAT examinations

TABLE 4-15: LC-2: PHYSICAL AND CHEMICAL CHANGE

Summary of Mean Scores of Composite Classes

		Classes		
		11-14	16-25	21-22
CAT 1	concrete	47.4	45.7	53.6
	formal	54.2	52.6	53.5
CAT 2	concrete	50.6	48.4	53.2
	formal	59.5	63.5	58.2
CAT 3	concrete	38.8	42.4	45.4
	formal	52.7	58.3	48.7
CAT 4	concrete	64.0	50.9	55.4
	formal	65.2	71.6	65.0

TABLE 4-16: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANOVA for CAT 1-4, Developmental Level by Composite Classes

Source of Variation	DF	Mean Square	F	P	
CAT 1: Pretest					
Class	2	229	0.94	0.40	
Developmental Level	1	679	2.78	0.10	*
Class X Level	2	178	0.73	0.73	
Error	127	245			
CAT 2: Post Phase I					
Class	2	8	0.05	0.95	
Developmental Level	1	3015	19.12	0.0001	*
Class X Level	2	307	1.94	0.15	
Error	128	158			
CAT 3: Post Phase II					
Class	2	247	1.23	0.30	
Developmental Level	1	3871	19.26	0.0001	*
Class X Level	2	518	2.58	0.08	*
Error	125	201			
CAT 4: Post Phase III					
Class	2	203	1.01	0.37	
Developmental Level	1	3442	17.13	0.0001	*
Class X Level	2	986	4.91	0.009	*
Error	123	201			

* Statistically significant

TABLE 4-17: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANOVA for CAT 1-4, Developmental Level by Composite Classes
Summary of significant test between Means Using Newman-Keuls ($\alpha = 0.10$)

CAT 1: formal > concrete

CAT 2: formal > concrete

CAT 3: formal > concrete
class 11-14 formal > class 11-14 concrete
class 16-25 formal > class 16-25 concrete

CAT 4: formal > concrete
class 16-25 formal > class 16-25 concrete
class 21-22 formal > class 21-22 concrete
class 11-14 concrete > class 16-25, 21-22 concrete

than concrete students on all four CAT scores. It can also been seen that there is no main effect for classes in any of the CAT scores with these combined courses. CAT 3 does have an interaction effect between class and developmental level. However, this interaction can be accounted for by the formal students in composite classes 11-14 and 16-25 scoring better than the concrete students in the same classes. What this seems to indicate is that sequences EG and GE, neither of which has an invention discussion, favor formal operational students. This doesn't seem too surprising. Formal operational students should better cope with the lack of an invention phase. Furthermore, sequences IG and IE also favor formal operational students. These two sequences require students to cope with the concept without the benefit of a concrete introduction. It follows then, that the two sequences where the I phase follows an activity favors neither formal nor concrete operational students.

CAT 4 shows an interaction effect between the concrete students for classes 11-14 and the concrete students of the other two combinations, 16-25 and 21-22. The 11-14 classes (those where the invention phase comes last) did better than combinations where the invention was first or was second. In both of these cases the EG combination acts as one long gathering the data phase for both 11 and 14 followed by an invention phase after which the post-test was given. One interpretation of this information might be that concrete students seem to need some sort of a laboratory/experience prior to the invention. For formal operational students, sequences where the I phase is first or second seem to have some advantage. At least this seems to be true for concepts like this one, which are relatively simple and for which students might have some previous knowledge. The analysis of covariance studies illustrated in Tables 4-18 and 4-19 show a similar pattern to the analysis of variance.

TABLE 4-18: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANCOVA for CAT 1-4, Developmental Level by Composite Classes
using pre test (CAT 1) as a covariate.

Source of Variation	DF	Mean Square	F	P	
CAT 2: Post Phase I					
Class	2	20	0.13	0.88	
Developmental Level	1	2117	14.40	0.0002	*
Class X Level	2	260	1.77	0.18	
CAT 1	1	1896	12.89	0.0005	
Error	121	147			
CAT 3: Post Phase II					
Class	2	366	1.94	0.15	
Developmental Level	1	2446	12.98	0.0005	*
Class X Level	2	347	1.84	0.16	
CAT 1	1	2703	14.35	0.0002	
Error	123	188			
CAT 4: Post Phase III					
Class	2	199	1.15	0.32	
Developmental Level	1	1936	11.24	0.001	*
Class X Level	2	752	4.36	0.01	*
CAT 1	1	2526	14.66	0.0002	
Error	123	172			

* Statistically significant

TABLE 4-19: LC-2: PHYSICAL AND CHEMICAL CHANGE

Summary of Least Square Mean Scores of Composite Classes

Summary of Significance Test Between LS Means Using Newman-Keuls (α =0.10)

		Classes			
		11-14	16-25	21-22	Summary of Newman-Keuls
CAT 2	concrete	51.5	49.3	52.9	formal > concrete
	formal	58.4	63.1	57.4	
CAT 3	concrete	39.9	44.2	45.5	formal > concrete
	formal	50.7	57.9	48.2	
CAT 4	concrete	65.3	54.3	55.7	formal > concrete class 16-25 formal > class 16-25 concrete class 21-22 formal > class 21-22 concrete class 11-14 concrete > class 16-25,21-22, concrete
	formal	64.3	70.7	64.6	

Trend Analysis. A trend analysis of the CAT scores from 1 to 4 was carried out as essentially a repeated measure analysis of variance on the CAT scores for each class done separately. The summary of this analysis of variance can be found in Tables 4-20 and 4-21. Since this trend analysis was in essence a test over time, from pre-test to post-test for each of the classes, it's not surprising to see a significant difference between tests (pre-test to post-test) for each of the six classes. An analysis of the sequences can be found in the summary table 4-21 using the Newman Keuls.

Class 11 has a EGI sequence. Analysis of the CAT scores shows a jump in knowledge after the E phase, a decrease in knowledge after the G phase and then an increase again to its highest level after the I phase. One interpretation of this is that the E phase, because of its length of time and richness of different materials may act as a self-contained learning cycle and, therefore, explained the jump in the knowledge from CAT 1 to CAT 2. However, in Section 21 as we'll discuss later, which also has an initial E phase, there is no such significant jump, although there is an increase in the mean. The decrease after the G phase may indicate that there is some confusion about the issues brought up in the E phase which have not been solidified because of no invention phase up to this particular time. This decrease may be a result of the length of time which the students are doing a number of different activities, none of which has solidified the concept, because no invention has occurred yet. The final CAT score indicates an increase over all of the first three CAT scores. This indicates that the I phase has served to solidify at this point at least the concept and may have confirmed some of the information that was previously learned for CAT 2.

Class 14 has a GEI sequence. The pre-test score from this particular class was high relative to the other classes indicating already a certain amount of knowledge of the information. As a consequence, the information going from CAT 1 to CAT 2 to CAT 3, that is from the post-G to the post-E scores, are relatively

TABLE 4-20: LC-2: PHYSICAL AND CHEMICAL CHANGE

Trend Analysis for CAT 1-4 for Each Class (ANOVA)

Source of Variation	DF	Mean Square	F	P	
Class 11: Sequence EGI					
Tests	3	1852	17.78	0.0001	*
Error	64	104			
Class 14: Sequence GEI					
Tests	3	677	2.46	0.07	*
Error	56	275			
Class 16: Sequence IGE					
Tests	3	1344	4.69	0.005	*
Error	84	286			
Class 21: Sequence EIG					
Tests	3	976	4.09	0.01	*
Error	72	238			
Class 22: Sequence GIE					
Tests	3	988	5.23	0.003	*
Error	64	189			
Class 25: Sequence IEG					
Tests	3	716	3.55	0.02	*
Error	84	202			

TABLE 4-21: LC-2: PHYSICAL AND CHEMICAL CHANGE

Trend Analysis for CAT 1-4 for Each Class (ANOVA)

Summary of Significance test between Means Using Newman-Keuls (α = .10)

Test	Means	Significance
Class 11: Sequence EGI		
CAT 1	47.6	
CAT 2	58.0	> CAT 1, 3
CAT 3	42.8	
CAT 4	66.1	> CAT 1, 2, 3
Class 14: Sequence GEI		
CAT 1	58.7	
CAT 2	52.6	
CAT 3	49.3	
CAT 4	64.5	> CAT 3
Class 16: Sequence IGE		
CAT 1	45.4	
CAT 2	54.8	
CAT 3	53.7	
CAT 4	64.5	> CAT 1, 2, 3
Class 21: Sequence EIG		
CAT 1	47.6	
CAT 2	54.1	
CAT 3	52.0	
CAT 4	64.5	> CAT 1, 2, 3
Class 22: Sequence GIE		
CAT 1	57.5	> CAT 3
CAT 2	58.2	> CAT 3
CAT 3	42.5	
CAT 4	57.5	> CAT 3
Class 25: Sequence IEG		
CAT 1	54.3	
CAT 2	58.4	< CAT 3
CAT 3	47.3	
CAT 4	60.2	< CAT 3

flat. The E phase in this particular case doesn't act as a self-contained learning cycle because there is no increase in knowledge after the exploration phase is completed. The only significance here is between CAT 3 and CAT 4. The overall effect was to increase the knowledge from pre-test to post-test. However, there is only an increase from the third to the fourth CAT score indicating the dip, the small non-significant dip, from CAT 2 to CAT 3 allowed a significant difference between CAT 3 and 4 which did not occur from CAT 1 to CAT 4.

Section 16 had the IGE sequence. This particular sequence going from I to G showed rather flat change in response. The post-I score and post-G score are both very similar to the pre-test. There was a significant increase after the E or exploration phase indicating that cumulatively the three phases seem to result in a significant change in knowledge of the concept. The post-E is significantly higher than any of the previous CAT tests.

Section 21 had a similar sort of pattern to Section 16. The results are rather flat up until the post-test in which case there is an increase that is greater than any of the three previous tests.

Section 22 had a GIE sequence. This was the control group. The results here are relatively flat with a dip in the post-I phase to a low score. However, this low score is similar to the low score in other phases. The confusing part about this particular learning cycle was that it had a relatively high pre-test score which was not much different from pre-test to post-test.

Section 25 was relatively flat with a dip at CAT 3 in a similar sort of pattern to Section 22. This particular section also had a relatively high pre-test score.

Over all there is little evidence for the importance of a sequence in this trend data. There does seem to be some evidence that a cumulative effect of all three phases is important for an increase in knowledge. There also seems to be some evidence that the knowledge varies throughout a lesson. That there are increases in knowledge and then also decreases in knowledge as the lesson goes on. Some activities may confuse students and cause them to question the fragile concepts that they were building during the earlier phases of the lesson. There is also some evidence (high average pre-test scores) that some students in some of the classes had had some previous knowledge of this particular concept which may account for the relatively flat distribution of CAT 1 to CAT 4 scores in many of the sections.

Achievement Analysis (Necessity)

As indicated in Table 4-2 the CAT data from Learning Cycle 2 can be used to artificially generate necessity experiments as well as be used in sequence experiments. Table 4-22 summarizes a comparison between CAT 4 of class 22, which is the control sequence, with the CAT 2 and 3 scores for each of the six classes. These tests compare the control learning cycle which has all phases, with learning cycles which are missing one or two phases. In studying the data on Table 4-22 only three significant differences are shown where the CAT 4 score for class 22 is significantly higher than the class 2 and 3 scores. These included class 22 CAT 3, class 11 CAT 3, and class 25 CAT 3. The first of these (CAT 3 from class 22) indicates the necessity of the exploration phase to the overall score of this learning cycle. The CAT 3 score from class 11 indicates the necessity of the I phase and the CAT 3 score from class 25 indicates the necessity of the G phase. This data is far from significant, however, when compared with all of the other CAT 2 and 3 scores which show no significant differences. The evidence for the necessities of the phases is not unambiguous from this data.

Another approach to the necessity question is to compare class differences in post G, post I, and post E scores no matter where in the sequence that phase fell. For example, a post G score would look at the importance of the gathering the data phase alone, in combination with E or I, and finally as an overall

TABLE 4-22: NECESSITY & NECESSITY X SEQUENCE VARIABLES

Compare Completed Control Sequence LC 24 Class 22 vs. LC 22 & LC 23 of other Classes

CL	CAT	$\bar{X}$	S.D.	N	d	SE	t	df	p
22	4	54.91	15.3	23	-	-	-	-	-
22	2	57.09	8.18	21			-.68	20	
22	3	43.00	13.23	21			3.48	20	**
11	2	56.67	10.2	21	1.76	3.89	1>t		
11	3	42.58	8.93	19	-12.33	3.79	3.25	40	**
14	2	51.47	14.85	17	-3.44	4.81	1>t		
14	3	47.11	18.23	18	-7.8	5.35	1.45	39	NS
16	2	52.6	19.23	25	-2.31	5.00	1>t		
16	3	52.39	18.74	23	-2.52	5.04	1>t		
21	2	53.75	12.20	24	-1.16	4.04	1>t		
21	3	50.61	17.62	23	-4.3	4.87	1>t		
25	2	57.44	12.92	25	2.53	4.11	1>t		
25	3	46.42	11.76	26	-8.49	3.94	2.16	47	*

* = .05
** = .001

TABLE 4-23: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANOVA Post G, Developmental Level by Classes

Source of Variation	DF	Mean Square	F	P	
Class	5	2704	5.74	0.0001	*
Developmental Level	1	4329	22.96	0.0001	*
Class X Level	5	529	1.12	0.35	
Error	115	188			

Significance test between Means using Newman Keuls

	concrete	formal	Summary of N-K	
Class 11	39.2	48.3		formal > concrete
Class 14	47.1	56.4	> 11	
Class 16	42.9	59.7	> 11	
Class 21	57.5	70.9	> 11, 16, 14	
Class 22	56.1	58.9	> 11, 16, 14	
Class 25	50.4	71.2	> 11	

TABLE 4-24: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANCOVA Post G, Developmental Level by Classes using pretest as covariate

Source of Variation	DF	Mean Square	F	P	
Class	5	1082	6.52	0.0001	*
Developmental Level	1	2380	14.34	0.0003	*
Class X Level	5	128	0.77	0.5726	
Pre test	1	1982	11.94	0.0008	
Error	109	166			

Significance test between LS Means using Newman Keuls

	concrete	formal	Summary of N-K	
Class 11	40.5	48.7		formal > concrete
Class 14	47.9	51.9		
Class 16	46.4	60.7	> 11	
Class 21	59.4	71.1	> 11, 14, 16,22	
Class 22	54.3	57.3	> 11	
Class 25	54.0	68.8	> 11, 14	

situation with a completed learning cycle although not in sequence. Table 4-23 and 4-24 summarize the analysis of variance of developmental level by classes of the post G scores, and the ANCOVA post G scores of developmental level by classes using the pre-test as a covariant. The pattern for the analysis of variance and the analysis of covariance in this particular case is similar. There are significant means effects for both classes and developmental level in these post G tests. Studying the analysis of covariance results with Newman Keuls test between means shows that class 21, 22, and 25 has significantly higher scores than combinations of 11, 14 and 16. Class 21, which is the EIG sequence and which has a completed learning cycle with G and E reversed from the control situation, could be argued as being a control like situation where E and G change roles. This particular post G sequence has significantly higher scores than section 11 which is an EG combination with no I, sections 14 and 22 which is G alone without either E or I, and with 16 which has I and G but no E phase. This data seems to support the idea that it's necessary to have all three phases in order to get a maximum score on the post-test. Section 25 also has all three phases, although the sequence is IEG. It is significantly greater than 11, which has no I, and 14 which has neither E or I phases. Taken together Sections 21 and 25 are the only post G scores which have completed all three phases. This again lends support to the idea that all three phases are necessary. Section 22 which just has a G phase is greater than section 11, which has both a G and an E phase. Neither one of these learning cycles is complete and the information might only be explained by differences between sections 22 and 11.

Post-I. The post-I data found in Table 4-25 and 4-26 also support the idea of a completed learning cycle, even though out of sequence, being necessary for maximum learning to take place. Section 11 and 14 post-I are the two sections which have completed learning cycles and according to the analysis of variance data both of these classes have higher scores than Section 16, 21 and 22, which

TABLE 4-25: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANOVA Post I, Developmental Level by Classes

Source of Variation	DF	Mean Square	F	P	
Class	5	1576	7.74	0.0001	*
Developmental Level	1	1395	6.85	0.01	*
Class X Level	5	617	3.03	0.01	*
Error	118	204			

Significance Test between Means using Newman Keuls

Class	Concrete	Formal	Summary of N-K	
11	66.2	63.6	> 16, 21, 22	formal > concrete
14	60.6	66.7	> 16, 21, 22	Class 11 concrete > 16,21,22, 25 concrete
16	41.5	61.3	> 22	
21	44.5	56.2	> 22	Class 14 concrete > 16,21,22 concrete
22	46.1	37.5		Class 25,14,11,16,21 formal > 22 formal
25	52.8	67.2	> 22, 21, 16	

TABLE 4-26: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANCOVA Post I, Developmental Level by Classes Using Pretest as Covariate

Source of Variation	DF	Mean Square	F	P	
Class	5	1633	8.69	0.0001	*
Developmental Level	1	643	3.42	0.07	*
Class X Level	5	435	2.31	0.05	*
Pretest	1	2666	14.18	0.0003	
Error	111	188			

Significance Test between LS Means Using Newman Keuls

Class	Concrete	Formal	Summary of N-K	
11	68.1	65.8	> 22,21,16	formal > concrete class 11 concrete > 22,16,21,25 concrete class 14 concrete > 22,16,21 concrete class 11,25,14,16,21 formal > 22 formal
14	61.2	62.6	> 22	
16	45.1	62.1	> 22, formal > concrete	
21	46.8	55.8	> 22	
22	44.0	36.2		
25	53.2	64.3	> 22	

which are missing GE, G, and E, respectively.

Post E. The data to compare the post-E scores among the different classes is summarized in Table 4-27 and 4-28. In studying the analysis of covariance Table 4-28, one can see that Section 16 which has the IGE sequence is greater than Sections 14, 25, and 21 which have no I phase, no G phase, and no I or G phase, respectively. Section 22, which also is a completed learning cycle, is greater than 14 which has no I phase and 25 which has no G phase. Section 11 and Section 21 which have only E phases, which one might hypothesize would serve as a self-contained learning cycle, are greater than Section 14 which would have no I and Section 25 which would have no G phase. Once again this lends support to the idea that all three phases of the learning cycle are necessary in order for maximum learning to occur.

Conclusions

In general, there is spotly evidence from this learning cycle that the sequence of the phases of the learning cycle is important. There is, however, good evidence from this experiment that all phases of the learning cycle are necessary for maximum learning. There is some indication that formal students can take advantage of concept invention as a first phase but little evidence that concrete operational students can take advantage of that sequence. Concrete operational students are more likely to learn in sequences where concept invention comes last. There is some evidence that knowledge fluctuates during a lesson. That a concept which might be well understood at the beginning of the lesson might loose some of its understanding through the confusion of the activities during a later part of the lesson. However, when all phases of the learning cycle are taken into account the learning finally seems to be solidified as well as it's going to be. There is some indication, although this is ambiguous, that E and G might be interchangeable and that E as a phase may act as a mini-learning

TABLE 4-27: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANOVA Post E, Developmental Level by Classes

Source of Variation	DF	Mean Square	F	P	
Class	5	631	4.04	0.002	*
Developmental Level	1	4700	30.12	0.0001	*
Class X Level	5	231	1.48	0.20	
Error	125	156			

Significance Tests between Means Using Newman Keuls

Class	Concrete	Formal	Summary of N-K	
11	53.0	62.6	> 14	formal > concrete
14	38.1	56.1		
16	51.6	71.8	> 14, 25	
21	49.8	57.7		
22	53.9	56.9		
25	42.1	56.1		

TABLE 4-28: LC-2: PHYSICAL AND CHEMICAL CHANGE

ANCOVA Post E, Developmental Level by Classes Using Pretest as Covariate

Source of Variation	DF	Mean Square	F	P	
Class	5	938	6.92	0.0001	*
Developmental Level	1	2987	22.06	0.0001	*
Class X Level	5	589	0.94	C.46	
Pretest	1	2943	21.74	0.0001	
Error	117	135			

Significance Tests between LS Means Using Newman Keuls

Class	Concrete	Formal	Summary of N-K	
11	54.5	64.9	> 14, 25	formal > concrete
14	38.8	51.9		
16	55.4	72.0	>14, 25, 22, 21	
21	51.7	57.3	>14, 25	
22	52.7	56.0	> 14, 25	
25	42.2	53.1		

cycle at least for formal operational students. Of course all of this information must be modified by the idea that the content of physical and chemical change which is found in this learning cycle might be relatively easy for many students because of previous exposure and as a consequence the sequence of the lesson may become irrelevant because of this earlier experience with the concept. At the same time there is some indication that at least some students have misconceptions concerning physical and chemical change and that these misconceptions prevail throughout the lesson. The information from this experiment must also be modified by the understanding that the tests themselves may have been ambiguous as to the concept of physical and chemical change and as a consequence might have washed out any of the sequence effect that we would have otherwise noticed.

CHAPTER FIVE

LC-5: CONSERVATION OF WEIGHT AND ATOMS

A Necessity Experiment

Experimental Design

This learning cycle was designed to teach the concepts of Conservation of Atoms and Conservation of Weight. As invented during the activities of LC-5 the concepts were stated as follows: (1) compounds consist of a definite proportion of elements by weight, and (2) compounds consist of a specific proportion of numbers of atoms. The application of these concepts was stressed during the activities of LC-5. Constant and multiple proportions were used to determine formulas for compounds.

LC-5 was designed as a necessity experiment (see also LC-8). Table 5-1 summarized the experimental plan for manipulations of the necessity variable. Five chemistry classes were involved. Each of these classes were assigned as control or experimental groups. The four groups tested the necessity of a phase of the learning cycle by eliminating it. In the case where the C phase is

TABLE 5-1

LC-5 Experimental Plan

Class	Phase 1	Phase 2	Phase 3
	pretest Form A CAT 1		posttest Form B CAT 2
11	G	no I	E
14	G	I_1	no E
16*	G	I_1	E
22	G	I_2	no E
25	no G	I_2	E

*Control

eliminated (IE), the lesson begins with the invention discussion. However, the invention discussion normally is based upon the data gathered during the G phase. Since no data was gathered, the project staff felt an I discussion would be awkward and would degenerate into a lecture. Consequently, it was decided to organize this phase into a lecture format to begin with. Since the control group I phase was organized as a discussion, it was recognized that the form of the experiment would be changed in this case. This confounding effect limits the comparisons which can be made. To help the comparisons it was decided to have two GI groups: (1) one with the I as a lecture (GI_2) and one with the I as a discussion (GI_1). This also allows a necessity X form interaction which can be tested.

It was also recognized by the project group that in a necessity experiment (as well as in a sequence experiment), the nature of the experiment could effect how the phase was used by a student. In other words, if no G phase is present the student might treat the I phase as a G phase or a combination GI phase. Two forms (A and B) of the CATs were developed for LC-5. The two forms were not designed to be equivalent. The A form was designed to test if students had prior knowledge of the content. The B form was used as a post-test.

Description of Classroom Activities

Learning Cycle 5 was used as a Necessity Experiment. A learning cycle normally has three phases: a Gathering Data phase (G), an Invention phase (I), and thirdly, an Expansion phase (E). This experiment was designed to test the necessity of each of the three phases. Therefore, each class would leave out a different phase of the learning cycle. Each phase was conducted as much like a normally run learning cycle as possible. The exception to this rule was when gathering data was the phase to be deleted. Since the invention phase is normally a discussion of the data collected during the gathering data phase, the invention had to become a lecture over the same material (See Appendix 5B). Student handout materials used during LC-5 have been reproduced in Appendix 5A.

TABLE 5-2

LEARNING ACTIVITIES FOR LEARNING CYCLE 5

LC Classroom Activities

Section Day	11 GE	14 GI#1	16 Control GIE	22 GI#2	25 IE
1	G lab Sections A-C (5A-2)	G lab Sections A-C (5A-2)	G lab Sections A-C (5A-2)	G lab Sections A-C (5A-2)	Invention Lecture (5B-4)
2	G lab Sections D-G (5A-2, 5A-3)	G lab Sections D-G (5A-2, 5A-3)	G lab Sections D-G (5A-2, 5A-3)	G lab Sections D-G (5A-2, 5A-3)	E lab Part I, Part II Sections A-D (5A-5)
3	G lab Sections G-J (5A-3)	G lab Sections G-J (5A-3)	G lab Sections G-J (5A-3)	G lab Sections G-J (5A-3)	E lab, Part II Questions (5A-6, 5A-7)
4	E lab Part I, Part II Sections A-D (5A-5)	Idea Questions Small Group Discussions of Questions (5A-4)	Idea Questions Small group Discussion of Questions (5A-4)	Idea Questions (5A-4)	Discuss E (5B-5)
5	E lab, Sections E-I, Questions (5A-6, 5A-7)	Invention Discussion (5B-2, 5B-3)	Invention Discussion (5B-2, 5B-3)	Invention Lecture (5B-4)	Reading & Questions Discussion (5A-8 through 5A-13)

(continued)

LC-5 Classroom Activities (continued)

Section Day	11 GE	14 GI#1	16 Control GIE	22 GI#2	25 IE
6	Discuss E (5B-5)	Invention Discussion Continued	Invention Discussion continued	Invention Lecture continued	---------
7	Reading & Questions Discussion (5A-8 through 5A-13	---------	E lab Part I, Part II Sections A-D (5A-5)	----------	--------
8	-------	---------	E lab, Part II Sections E-I Questions (5A-6, 5A-7)	---------	------
9	--------	----------	Discuss E	------------	---------
10	--------	-----------	Reading & Questions Discussion	------------	----------

The specification of classroom activities by sequence and class days is summarized in Table 5-2. Appropriate Appendix page numbers are given in parentheses to refer to curriculum materials utilized.

Post-Investigation Discussion

At the end of Learning Cycle 5, the two participating teachers and the principal investigator taped a discussion about their classroom observations concerning personal and student reactions to the learning cycle just completed. Since Learning Cycle 5 was a necessity experiment, most of the discussion centered on the need for the various parts of the learning cycle.

One of the major reactions of the instructors and the principal investigator from their observations had to do with the need for the invention discussion. One of the teachers remarked about the discomfort class 11 had with not having an invention discussion. "When I came in to do the expansion after the gathering the data section they said, "well, we're going to talk about the other lab", and I said, "No, we're going to do another laboratory and they said, "Why?" They wanted to discuss the results of the laboratory and they weren't happy about doing another laboratory before discussing the last one.

Because the expansion activity had some discussions in it, this teacher felt that the expansion served, when they discussed the expansion laboratory, as a mini-invention. The exploration laboratory and the discussion that followed it, was forced into the mold of providing the information that would have been in the invention if an invention discussion had occurred. The students forced an invention discussion through their questions and other interactions with the teacher. The students kept bringing up the points that needed to be discussing during the expansion discussion.

The other teacher who had class 25, where no gathering the data phase was utilized, also commented on the necessity of the expansion phase of the learning cycle. He commented, "As we got finished with the invention lecture and everybody said, 'yes, this is fine', then we went ahead and did the expansion. It was really as if we had not done the invention discussion at all. Basically the students treated the expansion as if they were starting all over again and treated the expansion then as a mini-learning cycle complete in its own right."

In furthering the discussion of the need for the expansion, both teachers noted their feeling that the control group, Section 16, seemed to make most of the gain in learning during the expansion part of the lesson. One of the observers stated, "The thing that really impressed me was how much that last lesson really was used by students to put their thoughts together. They really seemed to make a lot of gains at that point. Up to that point they seemed confused. During that lesson, however, they seemed to really put together things. It was very impressive to watch in the class. Students were interacting with each other. There were a lot of good ideas that came out of the classroom discussion. People were way ahead of the discussion. That was the interesting part. I remember one incident when the teacher asked them about the nitrogen oxide compound. They jumped right to the N_2O_5 formula without going through the rest of the intermediate compounds first. They went directly to the right answer." From this observational information there seemed to be evidence for the necessity of the expansion phase. This is an interesting result because most of the staff felt, before the project began, that if any one of the phases of the learning cycle might be unnecessary it would be the expansion phase. During this post-investigation discussion there was also some talk about the two different formats of the invention, one of which was a discussion, the other a lecture. Although there was some feeling among the discussants that the lecture was inferior to the discussion, there was no real evidence other than a feeling that supported this conclusion.

Case Studies

During the lesson of Learning Cycle 5, one student was randomly chosen from each of the five classes for in-depth interviews about their learning about and attitude towards learning cycle 5. The students in each class are not considered to be necessarily representative of their class, however, insights into student learning concerning the concepts associated, and some insight into other data that was collected can be derived from these case studies. Each case study was interviewed before the lesson began and after each of the phases of the learning cycle that the class went through.

Case Study 10. The teacher described this student as quiet and studious. He was conscientious concerning his classwork, asking quiestions on a one-to-one basis if clarification was needed. During the fourth nine week grading period, his overall grade dropped. This was attributable to work not being finished after a long absence from class. See Table 5-3 for a profile of CS-10.

The case study was in Class 11. During this Necessity Experiment, the class went through the gathering data and expansion phase of the learning cycle omitting the invention phase entirely. Three interviews were held with case study 10: (1) the first interview which was to determine if the student had any prior knowledge or misconceptions concerning the idea of the investigation, (2) the second interview which would show any changes in the thoughts of the student resulting from the gathering data phase of the learning cycle, and (3) the final interview which would ascertain the student's grasp of the concept after the expansion phase as well as the investigation as a whole. The interviews will be referred to as (1) pre-interview, (2) post-G interview, and (3) post-E interview respectively.

The central concept of learning cycle 5 was that compounds are put together in definite proportions by weight and number of atoms. The questions asked during these interviews were to ascertain the student's understanding and any misconceptions of this particular concept. Each interview asked three main questions: (1) What is the definition of a compound? (2) What are some examples of a compound and examples of something that is not a compound?, and (3) The student was

TABLE 5-3

CASE STUDY PROFILE

Student	10			
Sex	M			
Class	11			
Grade Level	12th			
Birthday	02-04-64			
I.Q.	106			
GEFT[1]	16	(Quartile 4)		
VH[2]	4			
FR[3]	4	6		
CC[4]	6	-		
Grades[5]	B	A	B	D

Variable Necessity

Group GE

LC 5 test scores (unadjusted)

CAT 1	0 %
CAT 2	67 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

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asked to give some quantitative information about hypothetical or real compounds.

During the pre-interview for CS-10 the student's definition of a compound was "A combination between two chemicals". His example was "hydrogen and oxygen joined together to form water." His example of something that was not a compound was hydrogen and oxygen by themselves. The case study exhibited a good qualitative, but not quantitative, grasp of the concept. He had an idea about atomic ratio and atomic weight as related to compounds; however, he was unsure of the application of these ideas to a particular compound. A quote from the pre-interview tape will illustrate this statement. The "I" will be used to designate a question of the interviewer and the "CS" will designate the case study's response.

I: Would a substance with the formula H_2O_2 be the same or different than water?

CS: It would be different.

I: Why? It is a compound made up of a mixture of hydrogen and oxygen also.

CS: It would have more oxygen than water would.

I: If I analyzed water, that is, break it apart into hydrogen and oxygen and found I had 8 grams of oxygen, could you tell me how much hydrogen I had in the water?

CS: I guess you could determine the ratio between the hydrogen and the oxygen.

I: What ratio is that?

CS: Like, two parts hydrogen to one part oxygen.

I: Does that mean I have 16 grams hydrogen?

CS: No, I don't think so. If one hydrogen weighed less or more than one oxygen by itself. So the hydrogen might weigh less than the amount of oxygen.

During the post-G interview the case study indicated he had assimilated the laboratory by describing the activites thoroughly; however, he had not accomodated the laboratory evidence. This was indicated by the fact that although he recognized the gas being given off during the laboratory activity as ammonia, his feeling was that the weight should remain the same (See Appendix 5A).

In reviewing the questions from the pre-interview the case study's idea of a chemical compound had remained much the same. There was not a reason after the gathering data to expect that it would change. As in the pre-interview, he spoke of compounds in terms of chemical reactions, that is, the compound is a substance formed by a chemical reaction. The following quotes will verify this statement.

I: What is a chemical compound?

CS: A combination between two chemicals.

I: What kind of combination and what kind of chemicals?

CS: A combination of atoms.

I: Can you give me some examples of compounds?

CS: Hydrogen and oxygen.

I: What is the compound? Is hydrogen and oxygen a compound?

CS: Yes.

I: Give me other examples of compounds.

CS: Calcium and nitrogen, if you can combine those?

I: What is the compound?

CS: Combination between those two atoms.

I: Can you give me examples of a material that is not a compound?

CS: Nitrogen by itself.

Concerning the case study's ideas of atomic ratio and atomic weight, similar quotes to those in the pre-interview written material can be found on the tape of the post-G interview.

During the Post-E interview the case study described the expansion laboratory activity thoroughly. He had assimilated and accomodated the laboratory evidence as shown by the way he asked the following question.

I: Would you describe what you did in the expansion activity?

CS: We heated $CuSO_4(H_2O_5)$. It charged from blue to white. Weights were taken before and after heating. It weighed less after heating.

I: Why?

CS: It lost water.

I: What was the source of the water?

CS: Hydrated copper (II) sulfate.

I: Was the hydrated copper (II) sulfate wet?

CS: No, the water was combined with the $CuSO_4$.

I: What was the residue?

CS: The white powder was $CuSO_4$.

I: You mentioned earlier that the system lost weight. What did you do with the weight change?

CS: We divided the weight change by the weight of the residue. Ours divided out to be 5.

I: What does that number represent?

CS: It represents x in the formula, $CuSO_4(H_2O_x)$.

The expansion activities included the reading, "The Chemical Congressman" (See Appendix 5A). There were three chemical laws discussed in this reading: (1) The Law of Constant Composition, (2) The Law of Multiple Proportions, and (3) The law of Conservation of Mass. The case study could not remember the names of the laws but seemed to have an understanding of the laws when asked specifically what a law meant. For example:

I: What does the Law of Multiple Proportions say?

CS: Two substances with the same kind of elements in both but the ratios are different.

I: Ratios of what?

CS: Numbers of atoms and by weight.

I: Would you give me an example of what you mean?

CS: One substance might have six carbons and one hydrogen and the other substance might have two carbons and one hydrogen.

The overall conclusion of the interviews with this case study is that although there was assimilation during the gathering data phase of the learning cycle that accommodation did not take place until during the expansion phase.

The case study gained considerable quantitative skill during the expansion phase of the learning cycle. The expansion apparently served as an invention mode for the student. This is easy to understand as the expansion consisted of a laboratory section, questions over the laboratory activity, a discussion of the laboratory and its questions and a reading. This sequence of material then was very similar to the gathering data, invention, expansion sequence of a regular learning cycle. As the quotes from the interview tapes show the case study demonstrated that he understood the concepts of learning cycle 5.

Case Study 32. The teacher described this case study as a student who seemed distracted from her class work. She was involved in a variety of school activities in a leadership role and also as a participant. Consequently, during many of the lessons her attention was on the other activities rather than the classroom lesson. Even though her "mind" was elsewhere, she was cooperative and friendly. See Table 5-4 for a profile of CS-32.

This was a Necessity experiment in which the G, gathering data, phase was performed as usual, the I, invention, phase was a class discussion, and the expansion was omitted entirely. There were three interviews scheduled with this case study: a pre-learning cycle interview, post-gathering data, and a post-invention interview. These will be designated as PRE-LC, post-G, and post-I interview respectively. The third interview with this case study was not held.

Each interview followed the same basic question line. The case study was asked to describe what activities they had been doing in class. Then the case study was questioned concerning their understanding of the concepts of learning cycle 5. Hopefully, during the interview, any misconceptions the case study had concerning the concept could also be found. The central concept of learning cycle 5 was that compounds are put together in definite proportion by weight and number of atoms. The three general questions asked were: (1) What is a chemical compound?, (2) Give some examples of materials which are compounds and materials which are not compounds., and (3) The student was asked to give some quantitative questions concerning either hypothetical or real compounds. There will be excerpts from the interview tapes used which will support the conclusions drawn about this case study's understanding or misconceptions of the concept in this learning cycle. In this quotation I will designate the questions of the interviewer and CS will designate the responses of the case study.

During the pre-LC interview the case study knew that a chemical compound was made up of more than one kind of atom. At times her answeres were not precise due to her lack of vocabulary of chemical terms. This interview being conducted in the early part of the year could be responsible for at least part of the lack of vocabulary.

I: What is a chemical compound?

CS: It is a combination of two substances to make one chemical.

I: When you say two substances, what do you mean?

CS: Hmm....

I: Let me ask you this way, could you give me an example of a compound?

CS: I could say carbon dioxide is a compound of carbon and.....I don't know the exact elements in it, but I know there's three elements in carbon dioxide.

I: Do you know the formula for it?

CS: CO_2.

I: CO_2, so it has carbon and...

CS: Oxygen.

TABLE 5-4

CASE STUDY PROFILE

Student	32				Variable	Necessity
Sex	F				Group	GI (discussion)
Class	14				LC 5	test scores (unadjusted)
Grade Level	11th					
Birthday	01-23-65				CAT 1	33 %
I.Q.	107				CAT 2	56%
GEFT[1]	8	(Quartile 1)				
VH[2]	3					
FR[3]	3	4				
CC[4]	5	5				
Grades[5]	B	C	B	B		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

I: Is that what you were talking about when you mentioned that it was made up of two substances?

CS: Right.

The next set of quotations from the pre-LC interview will illustrate that the case study had some misunderstandings concerning the significance of a chemical formula.

I: Carbon dioxide is CO_2 - what does CO_2 represent?

CS: The formula.

I: OK, what does the C and O_2 stand for?

CS: The C stands for carbon and the O_2 is for oxygen. I don't know if the C is in front of the O_2 or a certain reason or not.

I: Carbon monoxide is CO. Is there any difference between that and carbon dioxide?

CS: Yeah, there's a difference!

I: Would it be a different substance?

CS: Yeah.

I: OK now, in terms of formulas I gave you, CO and CO_2, what difference is there?

CS: The CO_2....what's the difference in those two, is that what you mean?

I: Yes.

CS: Carbon monoxide has carbon and monoxide in it, but carbon dioxide has carbon and oxygen.

To the third question of the pre-LC interview, the case study responded in the following way.

I: Let's take a hypothetical situation where we have a compound made up of two elements, X and Y. X and Y are not any particular elements. The compound's formula is XY. If we analyzed the compound, that is, break it apart to find that we have 5 g of X and 10 g of Y, how much would compound XY weigh?

CS: XY would probably weight 15 grams altogether.

I: What if you had 30 grams of XY, and you broke it down, what would you have then?

CS: Assuming that X is 5 and Y is 10 from the earlier one?

I: Yes.

CS: X would be 10 and Y would be 20.

The gathering data phase of the learning cycle consisted of a laboratory activity which the case study carried out with her lab partner. During the post-G interview the case study did not remember the laboratory activities until she was reminded. She then expressed that her understanding of the lab was not clear.

I: We have been doing a lab which involved the making of compounds. Did you feel like you understood what you were doing when you were in the lab?

CS: The one we did yesterday?

I: Yes, the one you finished up yesterday.

CS: Yeah,...I don't even remember. What was it?

I: Well, you started with a strip of metal ribbon.

CS: Oh yeah, that's right. I understood and everything, but I haven't understood it enough. Hopefully, I will come up with all the conclusions when we have the discussion.

The case study's definition of a chemical compound remained the same as it was in the pre-LC interview. The confusion shown in the pre-LC interview concerning the meaning of a formula still persisted. She was not focusing on the numbers of atoms represented by the formula but rather was confused by the momenclature.

I: Last time we talked about what a chemical compound is. Tell me what you think a chemical compound is now.

CS: Just the combination of two different substances combined together to form one substance.

I: We talked about some examples of a compound last time.

CS: CO_2.

I: What does CO_2 mean?

CS: One carbon atom and two oxygen.

I: I think we also talked about carbon monoxide.

CS: Yeah.

I: What is the difference between carbon monoxide and carbon dioxide?

CS: Carbon monoxide...is a different...carbon monoxide, I guess you can say, has monoxide in it and no oxygen but carbon dioxide...no, I guess they both have oxygen in them but the "di" and the "m" shows they are two different substances because one of them has dioxide and one of them has monoxide.

I: Do you know what monoxide means?

CS: No.

The post-I interview was not held with this case study. Therefore, there could not be any conclusions drawn concerning how the invention discussion affected the student's understanding and misconceptions of the concept of learning cycle 5.

Case Study 57. The teacher described this case study as a conscientious student. Although she had a visual handicap, she did not allow it to interfere with her class work. The student would hesitate to participate in class discussions, but she would ask for help on a one-to-one basis after class. When she was absent from class, the assignment was made up quickly. See Table 5-3 for a profile of CS-57.

The case study was in Class 16. For this Necessity experiment Class 16 served as the control group. The class activities were conducted as a normal learning cycle lesson would be. The lesson started with the gathering data phase, followed by the invention discussion, and then the expansion phase. The expansion phase of learning cycle 5 consisted of a laboratory activity, followed by student questions over the lab, a discussion of the lab, and a reading, (See Appendix A).

There were four interviews scheduled with this case study. They were as follows: (1) pre-learning cycle, (2) post-gathering data, (3) post-invention discussion, and (4) post-expansion. These will be designated as pre-LC, post-G

TABLE 5-5

CASE STUDY PROFILE

Student 57

Sex F

Class 16

Grade Level 11th

Birthday 09-65

I.Q. 117

GEFT[1] 11 (Quartile 2)

VH[2] 4

FR[3] 4 4

CC[4] 4 -

Grades[5] B A B A

Variable Necessity

Group GIE Control

LC 5 test scores (unadjusted)

CAT 1 33 %

CAT 2 78 %

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1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

post-I, and post-E respectively. The pre-LC interview was to determine if the student had any prior knowledge or misconceptions concerning the idea of the investigation. The post-G and post-I interviews would show any changes in the thoughts of the student resulting from either the gathering data or invention phase of the learning cycle. The post-E interview would ascertain the student's grasp of the concept after the expansion phase as well as the investigation as a whole.

The main concept of learning cycle 5 was that compounds are put together in definite proportions by weight and number of atoms. The questions asked during these interviews were to ascertain the student's understanding and misconceptions of this particular concept. The interviews followed the same basic pattern. First, the student was asked to review the class activities. Secondly, the case study was asked to respond to three standard questions. The questions are as follows: (1) What is a chemical compound?, (2) Give example of materials which are compounds and materials which are not compounds, and (3) The student was asked to give some quantitative information about hypothetical or real compounds.

During the summaries of the interviews excerpts from the interview tape will be used to illustrate the student's understanding or misconception of the concept of the learning cycle. For these quotations I will stand for the interviewers questions, and CS will designate the case study's responses.

During the pre-LC interview the student revealed that she had no knowledge of a chemical compound. When asked to give an example, she could not do so.

I: What is a chemical compound? What does it mean to you when someone says chemical compound?

CS: I know it would be a substance. Would it be a solid? No, it wouldn't necessarily be a solid. I don't think it would be just a solid or liquid. I can't explain it.

I: Can you think of something that would fall into the category of a compound - an example?

CS: I don't think so.

During the post-G interview the case study was able to describe the laboratory procedures, (See Appendix 5[illegible]). She has assimilated the laboratory evidence. The proof for this statement is in the following quotation. The case study was describing the laboratory.

CS: We substracted the first weight from the final weight. The weight we got after we heated it with the water was more than the first.

I: Do you think anything happened to the magnesium all the time you worked with it?

CS: Something had to happen because it weighed more. Maybe, it absorbed some of the water? Something happened because it weighed more.

In the foregoing statement the case study shows that although she has assimilated the laboratory evidence by recognizing the change in weight, she had not accommodated the information.

Realizing that she might be asked some of the same questions, the case study had looked in the dictionary to find the definition of a chemical compound. However, the answers she gave to questions concerning the definition reveal her lack of understanding.

I: Last time I asked you what a chemical compound is. Do you have any different ideas now?

CS: Yeah. It is kind of like...two or more elements joined together by proportional weight.

I: Where did you get those ideas?

CS: I looked it up in the dictionary.

I: When you talk about two or more elements, what are you referring to?

CS: Two different elements, can be liquids or solids.

I: Is water an element?

CS: Yes.

I: Is magnesium and element.

CS: Yes, I think everything's an element; air.

I: Is $FeCl_3$ an element?

CS: Not sure.

The post-I and post-E interviews were not held with this case study; therefore, there cannot be any conclusions drawn.

Case Study 97. Student 97 was a gregarious young lady, who was extremely involved in extracurricular activities. She participated freely in class discussions and she seemed to be uninhibited with regard to asking questions that would show a lack of understanding about a concept. She experienced difficulty in understanding more abstract ideas but she seldom reached the point of being frustrated with her attempts at understanding. There was, however, a noticeable decline in her academic performance late in the school year. See Table 5-6 for a profile of CS-97.

LC-5 was a necessity experiment during which the G phase was performed normally, the I phase was presented as a lecture, and the E phase was omitted. Three interviews were held with this case study: one prior to any work with the learning cycle, one following the completion of the G phase, and the final one after the I phase lecture. For purposes of the present discussion, these interviews will be designated as pre-LC and post-G and post-I, respectively.

The goal of each interview was to ascertain the level of knowledge, along with any misconceptions, relating to the central concept of LC-5. The concept is as follows: "Compounds are made up in definite proportions by weight and number of atoms." Three lines of questioning were pursued: (a) the case study was asked to provide examples of substances that are compounds and of substances that are not compounds; and, finally (c) the case study was asked quanitative questions relating either to hypothetical or real compounds.

The responses given by the case study during the pre-LC interview indicated that she had an idea that compounds must contain at least two different elements

TABLE 5-6

CASE STUDY PROFILE

Student	97			
Sex	F			
Class	22			
Grade Level	11th			
Birthday	10-21-64			
I.Q.	103			
GEFT[1]	-	(Quartile ____)		
VH[2]	3			
FR[3]	5	4		
CC[4]	2	6		
Grades[5]	B	B	B	C

Variable Necessity

Group GI (Lecture)

LC 5 test scores (unadjusted)

CAT 1 33 %

CAT 2 78 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

but she did not make clear an understanding that different formulas for compounds indicate differences in physical properties. The differences noted were differences in the formulas subscripts. She did, however, indicate an understanding that weight comparisons of elements could give definite information about a compound.

I stands for interviewer and CS stands for case study in the quotations that follow. Quotations used are edited excerpts from the interviews.

I: Define the term chemical compound.

CS: A compound is two or more substances that are mixed together...or put together.

I: Can you give an example of a compound?

CS: NaCl.

I: Can you give an example of a substance that is not a compound?

CS: Gold...it's not a compound. It's just a substance that has its own characteristics and it's different from anything else.

I: Sodium chloride is not a different substance?

CS: Well, sodium has its characteristics and then chloride has its characteristics and when the two are together they make their own new characteristics...after the mixing, after they have compounded.

I: Is carbon dioxide a compound?

CS: Yes.

I: What is the formula for carbon dioxide?

CS: CO_2.

I: Would a substance with the formula CO be the same as carbon dioxide?

CS: No, the 2 makes the difference.

I: Is C_2O_4 the same as CO_2?

CS: It might have the same substances but they are in different amounts. They are different because the numbers are not the same.

I: If we could break down CO_2, what would form?

CS: Carbon and dioxide.

I: If we analyzed the sample of CO_2 and found 6 g of carbon, how could you determine the amount of oxygen in the compound?

CS: Substract 6 g from the weight of CO_2.

I: Given another sample of a compound composed of carbon and oxygen has 12 g of carbon, is it the same compound or a different compound?

CS: If the proportions are the same, it will be the same... if the weights are proportional...you need to make a proportion of carbon and dioxide.

During the post-G interview, the interviewer also asked the case study some questions about the experimental procedure that had been performed. The procedure can be found in Appendix 5A. The case study expressed some interesting thoughts concerning the temperature of matter and the weight of matter.

I: Why did it (the experimental system) gain weight?

CS: I don't know. I thought we would lose weight. We had vapors given off (ammonia smell)...the flame from the burner caused some sparking...(there was) a little spattering.

I: Then did you really expect the weight to the the same; maybe less because of losses from the spattering?

CS: Yes. I don't know why it gained weight but when stuff is hot it expands but then it cooled back down.

I: Do things weigh more if they're hot?

CS: No...I don't know but they do expand.

The case study continued to base her answers, about differences in compounds, on the differences in formulas of compounds without referring to differences in properties that those compounds would have.

In this section of the interview the case study affirmed the definition given previously adding that she had checked with some other students following the first interview and they had agreed with her definition. The interviewer asked for examples of compounds.

CS: H_2O, carbon tetrachloride, potassium chloride.

The interviewer then asked for examples of substances that were not compounds.

CS: Zinc; any of those taken apart, like just potassium or chloride.

I: Is O_2 gas a compound?

CS: No...it is just a single substance; it has its own characteristics.

I: Is H_2O_2 a compound?

CS: Yeah.

I: Are H_2O and H_2O_2 the same or different?

CS: They're different because of the 2 down below; there's a different number of hydrogens to oxygen.

I: If I had a sample of H_2O and a sample of H_2O_2 and I analyzed them, and it turned out that I had the same amount of hydrogen in both samples, say 2 grams, how would the amounts of oxygen compare?

CS: There would be more oxygen in H_2O_2.

I: How much? Would there be twice as much or would you have to have more information?

CS: I think it would be double.

I: If I had 8 g of H_2O, could you figure out how many grams of hydrogen and oxygen I would have?

CS: If I had more information, I could.

I: What kind of information would you need?

CS: I'd need to know how much either H or O weighed.

The post-I interview indicates that the case study acquired a distorted definition for "compound" during the invention lecture and then she attempted to apply that definition to questions asked with limited success. Although she talked about ratios of weights of elements in a compound, her understanding seemed to be limited to ratios of numbers of atoms as indicated by the compound formula.

I: What is a compound?

CS: Two elements put together proportionally and by weight.

I: Can you give me some examples of compounds?

CS: FE_2Cl_3...has two elements and the proportion of 2:3.

I: Let's say you have 15 g of Fe_2Cl_3, how would you go about determining how much iron and chlorine you had in the compound.

CS: First, you'd find the weight of iron and chloride...multiply 56 x 2 = 112 and 35.5 x 3 = 106.5 then put Fe over Cl then put 112 over 106.5, and divide...now check and get your atomic weight of iron and your weight of chloride..

(At this point the student became confused about the problem and after stumbling for a while and asking several questions about the problem she and the interviewer agreed to leave that question for the time being.)

I: Let's say that I have a compound that contains iron and chlorine, it may be another compound or it may be this compound, but I want to check and see if it is this compound or another compound. What would I do and what would happen if it were the same compound?

CS: If it was the same compound, the weights would be the same; they would work out the same.

I: Do you mean that I would have 112 g of iron and 106.5 g of chlorine?

CS: Yes.

I: Well, what if I had 50 g of iron? Does that mean it couldn't be the same compound?

CS: No, it could be proportional; it could be the same; it could be divided out.

I: Divide what out?

CS: Two Fes to every three Cls.

I: OK, but I can't count the number of atoms. I just have this sample of a compound, say 30 g of this compound and I know it contains iron and chlorine. Is it this compound or is it some other compound? Maybe it's Fe_3Cl_3 or $FeCl_2$. How would I check it out?

CS: You'd have to separate it and see how much FE to how much Cl you had.

I: And, if it's the same compound what would you expect?

The case study stumbled at this point and was unable to continue with the problem.

I: We have a compound, say Fe_4Cl_6. Is that the same as Fe_2Cl_3?

CS: It's not the same, but its proportion is the same.

I: Is there any way I could tell that I had Fe_4Cl_6 instead of Fe_2Cl_3?

CS: You would have to go back to the weight again. That's half of it. If you find out that the proportions are the same, you have to make sure that the weights are the same. By the definition it has to be proportional and by weight.

I: Is there something you could do to tell if Fe_4Cl_3 were the same or different.

CS: I don't know for sure. I understand the proportional part of this, I don't understand the weight part of it.

The G phase of the learning cycle had little, if any effect on the case study's pre-conception of what a chemical compound is. Although the invention lecture served to change her definition somewhat, her responses point to the conclusion that her ability to reason with data about a compound had not changed significantly. There are signs, in the post-I interview, that she attempted to apply problem solving methods presented in the lecture to the questions being asked. That her understanding remained incomplete is evidenced by her inability to move completely through the problem of determining a formula from weight data.

Case Study 129. This student had considerable difficulty understanding the content of any of the learning cycles in the course. A significant contribution to the difficulty this student faced is the abstract nature of most of the concepts studied in the course. Other factors, however, such as short concentration span, sporadic involvement in class discussion and poorly developed memory skills contributed to the difficulties she had. Given all the difficulty she experienced with the content of the course, she did not express a negative attitude toward the course. See Table 5-7 for a profile of CS-129.

TABLE 5-7

CASE STUDY PROFILE

Student 129

Sex F

Class 25

Grade Level 12th

Birthday 09-25-64

I.Q. 102

GEFT[1] 10 (Quartile 2)

VH[2] 2

FR[3] 3 3

CC[4] 4 5

Grades[5] C C D C

Variable Necessity

Group IE

LC 5 test scores (unadjusted)

CAT 1 33 %

CAT 2 33 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

LC-5 was a necessity experiment. This case study was a member of the class in which the gathering data, G phase, was omitted and the I phase consisted of a teacher lecture to introduce the concept and the expansion of the idea, E phase, was performed, according to the materials in Appendix 5A.

Three interviews were conducted with this case study. The first interview was held prior to any interaction with the content of this learning cycle (pre-LC), the second interview occurred just following the invention lecture (post-I), and the final interview followed the completion of the expansion phase of the learning cycle (post-E).

The goal of each interview was to ascertain the level of knowledge, along with any misconceptions, relating to the central concept of LC-5. The concept is as follows: "Compounds are made up in definite proportions by weight and number of atoms." Three lines of questioning were attempted in each interview: (a) the case study was asked to define a chemical compound; (b) then the case study was asked to provide examples of substances that are compounds and of substances that are not compounds; and, finally, (c) the case study was asked quantitative questions relating either to hypothetical or real compounds.

The pre-LC interview showed a misconception, or possibly the lack of a usable pre-conception, of what a compound is. The responses given to the part of the questioning indicated that the case study confused "compound" with denisty or some other property of matter. The interviewer decided not to pursue the third line of questioning in this first interview. The following are quotations from the pre-LC interview. I stands for interviewer and CS stands for case study.

I: What is a chemical compound?

CS: I don't know.

I: If I were to ask you to give me an example of a compound, what would you say?

CS: When I think of a compound, I think of something that's compacted together.

I: Can you think of something that is not a compound?

CS: If it was liquid or something, that doesn't seem very compound. A solid would be more compound.

During the post-I interview, the case study recalled that a definition for chemical compounds was given during the invention lecture, but she was unable to reiterate the definition. She did, however, name a compound when asked for examples, but she was not able to give a reason for its being a compound. When given example formulas for compounds, the case study noted differences but gave no indication that she related the different numbers to different quantities of matter. The case study, by her own statement, has difficulty dealing with mathematical concepts and her answers show that she did not grasp the weight relationships of elements within a compound. Information given during the invention lecture can be found in Appendix 5B.

I: What is a chemical compound?

CS: One of the chemical things on the periodic table. I'm not sure if one of the chemicals is a compound, maybe some of them together.

I: Can you give me an example of a compound?

CS: Oleic acid.

I: What makes oleic acid a compound?

CS: I don't remember.

I: Your teacher gave you a definition of what a compound is and how to determine its formula. Do you remember that?

CS: It's amount of something with atoms and weight. I don't remember what he said, though.

I: If we had the formula CO, which is carbon monoxide, and we had the formula CO_2, would that be the same compound?

CS: No, because there's more of the O in the CO_2.

I: Does that make it a different compound?

CS: Yes, I think.

I: If we took a compound, XY, and broke it down and found that we had 5 grams of X and 10 grams of Y, how much would the compound XY have weighed?

CS: It would be 50, wouldn't it?

I: Why would you way it's 50?

CS: Well, I just figured it was 5 times 10. I don't know if it's right or not.

I: Given 30 g of XY, how many grams of X would there be?

CS: There would be 3 grams of X and 10 grams of Y.

I: How did you arrive at those numbers?

CS: I just looked at this (10 x 5, on a piece of paper) and 10 times 3 equals 30.

During the post-E interview the case study still showed the definiency of a clear definition of "chemical compound" but she had a much better idea of how to deal with weights in an elementary way. The concept of a ratio of weights apparently had no meaning for her but she was able to recite correct ratios of numbers of atoms for some compounds. There is evidence, in the questioning relating to copper (II) sulfate, that the case study did not have a good understanding of the significance of the subscripts within a compound formula.

I: What is a chemical compound?

CS: I'm not real sure; its a mixture of two different chemicals or substances.

I: Can you give me some examples of compounds?

CS: Copper (II) sulfate; water, carbon dioxide-CO_2.

I: Can you think of examples of substances that are not compounds?

CS: Carbon, because it's just by itself.

I: If we were to break copper (II) sulfate down and analyzed it what would we find?

CS: Two coppers and one sulfate; I'm not sure.

I: OK. The formula is $CuSO_4$.

CS: So, there would be four sulfates and one copper.

I: If I have the compound XY, and I analyze it and find 5 grams of X and 10 grams of Y, how much compound XY did I begin with?

CS: 15.

I: So, if I start with 30 grams of XY and analyze that how many grams of X will I have?

CS: 10 grams of X and 20 grams of Y because there were 5 grams the first time of X and I just doubled it.

I: Will I always have the same amount of X and Y every time I have compound XY?

CS: No, it depends on how much you have.

I: How about the ratio of X and Y; would that be the same?

CS: Probably, but I don't know.

I: Are H_2O and H_2O_2 the same?

CS: No, because there's more O in this one (H_2O_2).

I: What is the ratio of the atoms?

CS: This (H_2O) will be 2 to 1 and this (H_2O_2) will be 1 to 1.

I: Is there a way that when we get the weights of something in lab, we can get a formula from the weights we found in lab?

CS: Just what we were doing in class; use the periodic table to find out what each compound weighs or substances and then divide them into each other.

I: What does that tell?

CS: The weight of each one put together. I'm not sure.

The expansion phase of the learning cycle seemed to be the more important aspect of the development of any understandings gained by the case study. It probably served as a learning cycle in itself, in that there was a discussion of data that followed the laboratory work. Although the case study's definitions and understandings remained incomplete by the end of the experiment, she had made considerable progress from the first interview. Her lack of ability and confidence with mathematics may have served to inhibit her development of the concept. The methods presented for determining the formula of a compound from weight data were sufficiently involved to preclude memorization of a procedure without understanding some of the reasoning underlying the process.

Summary. To summarize some information gained from the case stuides, there seems to be support for the idea from case study 10, where no invention phase occurred, that the expansion phase serves as a mini-learning cycle. There is also some indication from this phase that although assimilation occurs with the gathering the data phase, accommodation doesn't occur until some sort of invention is made. Either a mini-invention during the expansion phase or an actual formal invention would be needed. Case Study 129, where there was no G, did not have a concept even after the invention. This indicates that perhaps the G phase is necessary at least for this student. Post-E also showed some deficiencies with this student, although certainly this particular phase was most important to the student's understanding, albeit incomplete understanding of the concept. However, case study 97, where there was no E, indicated that although the invention improved the knowledge of the concept somewhat the learning still remained incomplete. At last, for individual students then there is evidence from the case studies that all three phases of the learning cycle are necessary for a complete understanding of the concept. This conclusion, however, must be tempered by the possibility that even with all three phases the student's understanding might still be incomplete.

Achievement Analysis

Appendix 5C contains the two versions of the Concept Achievement Test utilized as pre and post-tests in this learning cycle. It also contains the grading criteria for the two forms of the CAT. The two forms were not considered equivalent. Form A which was used as a pre-test was used merely to illustrate that the students of the different classes had an equal amount of knowledge concenring the concept, prior to the lessons beginning. Table 5-8 summarizes the

TABLE 5-8. LC-5: CONSERVATION OF WEIGHT AND ATOMS

ANOVA for CAT 1 (Pretest) Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	1097	3.12	0.08	*
Class	4	295	0.84	0.50	
Class X Level	4	516	1.46	0.22	
Error	101	352			

Summary of Least Square Means

Level	CAT 1
concrete	32.5
formal	39.0

formal > concrete

Class	CAT 1
11	31.3
14	42.3
16	35.0
22	34.2
25	36.1

Class	concrete	formal
11	25.4	37.3
14	33.1	51.4
16	29.8	40.2
22	35.2	33.1
25	39.0	33.1

analysis of variance results which support these ideas. As can be seen from that analysis of variance, there is no main effect for class nor for class by developmental level interaction. There is a main effect concerning developmental level with formal students scoring better on the pre-test than concrete students. A study of the pre-test means also shows fairly low scores. From this analysis it will be assumed that the five classes involved in this experiment are equivalent to each other and that the pre-test knowledge of the concept being taught is minimal.

Table 5-9 summarizes the analysis of the post-test scores of the five classes involved in this experiment. Once again there is a main effect for developmental level with formal again out-scoring concrete students overall. There is also a main effect involving class. From that analysis and a Newman Keuls of the results it can be shown that class 16, the control group (the group that had all three phases) has significantly higher scores than section 14, which had no expansion activity. Studying the means of the CAT 2 (post-test scores) of the five classes gives further information about the nature of the different groups. The control group which had all three phases was overall the highest of any of the other groups. Two other groups which had close to those high scores was section 11 and 25. Section 11 had no invention phase. However, data from the case studies and classroom observations indicate that the E phase in this learning cycle might serve as a mini-invention. Section 25 has no G phase. From the observation cited earlier, the expansion phase seemed to serve as a mini-learning cycle. The other two sections, 14 and 22, were lower than the three classes just cited. Both of these sections had no expansion phase. Although the only significant differences, statistically, were between classes 16 and 14, the previous discussion seems to lend some support to the necessity of the expansion phase for this particular learning cycle.

This information along with the discussion of the observations and case

TABLE 5-9: LC-5: CONSERVATION OF WEIGHT AND ATOMS

ANOVA for CAT 2 (post test), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P
Developmental Level	1	11,104	24.08	0.0001 *
Class	4	1,036	2.25	0.07 *
Class X Level	4	459	0.99	0.41
Error	102	461		

Summary of Least Square Means

Level	CAT 2
concrete	59.8
formal	80.6

formal > concrete

Class	CAT 2
11	74.7
14	61.8
16	78.1
22	63.5
25	72.8

16 > 14

Class	Concrete	Formal
11	63.6	85.9
14	48.8	74.9
16	73.5	82.7
22	56.3	70.8
25	56.8	88.8

studies seems to lend further support to that hypothesis. In summary, the CAT data collected for this learning cycle lends support to the necessity of the expansion phase of the learning cycle. There is no evidence, either negative or positive, indicating the necessity of the gathering the data or the invention phase from this analysis.

Attitude Analysis

Attitudes toward the lesson was measured by the BAR Attitude Inventory, which is discussed in Chapter 2. The results of the BAR is represented in two factors, (1) a contentment factor, indicating how comfortable the student is with the lesson in general and (2) a comprehension factor, which is a measurement of their attitudes towards how they learned or comprehended the material that was taught in the lesson. An analysis of variance for each of these two factors is summarized in Tables 5-10 and 5-11.

Students were furthermore encouraged to write spontaneous comments concerning their attitudes toward the lesson on the reverse side of the BAR form. These comments are summarized on a tally sheet that can be found in Appendix 5B. The tally sheet tries to summarize each spontaneous comment made by the students insofar as whether they are negative, postive, or neutral, and whether they concerned the laboratory, the discussion-lecture, the demonstration, questions, problems, or readings associated with the lesson. The comments were further tallied as to indicate whether these statements expressed an attitude toward the lesson.

From Table 5-10 it can be seen that there is no differences between classes concerning the contentment factor on the BAR Attitude Inventory. Table 5-11 indicates that there is a main effect of differences between classes concerned with the comprehension factor. In this particular case the control group, class 16, was significantly higher than class 14, which represented no expansion activity.

TABLE 5-10: LC-5: CONSERVATION OF WEIGHT AND ATOMS

ANOVA for BAR Contentment Factor

Source of Variation	DF	Mean Square	F	P
Class	4	28.8	1.21	0.31
Error	103	23.8		

Least Square Means

Class	Contentment
11	28.9
14	26.8
16	30.0
22	29.5
25	29.3

TABLE 5-11: LC-5: CONSERVATION OF WEIGHT AND ATOM

ANOVA for BAR Comprehension Factor

Source of Variation	DF	Mean Square	F	P	
Class	4	56.9	2.09	0.09	*
Error	104	27.3			

Least Square Means

Class	Comprehension	
11	31.6	
14	30.1	
16	34.1	16 > 14
22	32.5	
25	30.5	

This pattern is similar to the pattern noticed in the post-test for the CAT analysis. This result might be interpreted to say that the control group, which had all three of the phases of the learning cycle, had a better attitude toward their comprehension of the concept than when the expansion phase is eliminated.

From the BAR written comments summarized in Appendix 5D it can be seen that there are a large number of positive comments concerning the laboratory in all of the sections, with the exception of class 25 which did not have a "gathering the data" phase. That group in fact had the smallest number of comments overall. Several students in class 11, which had no invention discussion after the "gathering the data" phase, mentioned that they would like to have had more classroom discussion after laboratories were over to make sure that everyone understood the ideas taught in the laboratory.

Conclusions

As was discussed earlier, there is ample evidence from both the CAT and the BAR that the E phase, the expansion phase, of the learning cycle is necessary for this particular learning cycle. There is also evidence from the observation and case study data that all three phases of the learning cycle are necessary. There is also an indication from the BAR written comments that the laboratory is an important function of learning cycle activities. Since these laboratory activities took part in both the gathering the data and the expansion phases of this learning cycle, this indicates some support for the necessity of those phases.

CHAPTER SIX

LC-7: SIMPLE CHEMICAL REACTIONS

A "LESSON CONTROL" FORM EXPERIMENT

Experimental Design

This learning cycle was designed to teach the concept of a simple chemical reaction. It was designed to build on the operational definition of physical vs. chemical change introduced in LC-2 and the knowledge of atoms and molecules gained in learning cycles leading into LC-7. The main thrust was to help students develop a theoretical concept of chemical reactions based around chemical equations. As invented during the activities of LC-5, the concept was stated as follows: chemical reactions involve change in combinations of atoms from reactants to products. In order to teach this concept several subconcepts and skills were also taught, including: (1) the skill and necessity of balancing chemical reactions, (2) predicting products for chemical reactions using evidence and logic, (3) types of simple chemical reactions, and (4) conservation of mass as related to chemical reactions.

LC-7 was designed as a "lesson control" form experiment (See also LC-14). This meant that the activities of each group was similar in content but varied in how the content was presented. In the "lesson control" form the primary source of information was varied. In the control group the source of information was the laboratory activity and the discussions. In experimental group T_1 the source of information was the teacher lecture. In experimental group T_2 the source of information was the teacher demonstration. In experimental group R the source of information was in readings. Tables 6-1 and 6-2 summarize the experimental plan for manipulation of the form variable. All three phases of the learning cycle were utilized in sequence.

TABLE 6-1

LC-7 Group Assignments

CLASS	ASSIGNMENT
11	T_1
16	R
22	Control
25	T_2

TABLE 6-2

LC-7 Testing Plan

	G	I	E		
pre-test				post-test	retention
Form A				Form B	Form B
CAT 1				CAT 2	CAT 3

Two nonequivalent forms of the CAT were developed. The A form was used to test if students had prior knowledge of the content. The B form was used as a post-test and as a retention test which was given six weeks after the post-test.

Description of Classroom Activities

This form experiment, which studied the effect of change of lesson control, involved four sections: one control group and three groups in which the control of the lesson varied. The control group moved through the learning cycle, as it was originally designed, with students collecting data in the Gathering Data (G)

TABLE 6-3

Form Experiment: Change of Lesson Control

	Control 22	Teacher 1 11	Teacher 2 25	Reading 16
G	Students collected data	Teacher presents data array with explanation of source of data	Teacher demonstrates and explains the laboratory work	Reading followed by student questions
I	Students orginize data; class discussion	Teacher* lectures with no planned student/teacher interaction	Teacher* lecture with no planned student/teacher interaction	Reading followed by student questions
E	Students collect data and answer questions; Class discussion; reading and questions	Teacher presents data array; Teacher asks questions from original laboratory; teacher lectures on reading materials and assigns questions	Teacher demonstrates the laboratory work and explains; Teacher asks questions from original laboratory; Teacher lectures on reading and assigns questions	Reading followed by student questions

*Although there is no attempt, in this mode, to involve students in a class discussion, the teacher dealt with any questions asked by the students during the lecture.

TABLE 6-4

LC-7 Classroom Activities

Section Day	Control 22	Teacher 1 11	Teacher 2 25	Reading 16
1	Gathering Data laboratory (6A-2 through 6A-4)	Data array and lecture (6B-4, 6B-5)	Demonstration of Gathering data laboratory (6B-9, 6B-10)	Gathering data reading 7A; answers questions (6A-15)
2	Complete laboratory and assign Idea questions (6A-5, 6A-6)	Invention lecture (6B-6)	Invention lecture (6B-6)	Invention reading 7B; answer questions (6A-16, 6A-17)
3	Invention discussion (6B-2, 6B-3)	Expansion data array and lecture (6B-7, 6B-8)	Expansion laboratory demonstration (6B-11)	Expansion reading 7; assign questions (6A-9 through 6A-14;6A-18, 6A-19)
4	Expansion laboratory (6A-7, 6A-8)	Lecture on reading material	Lecture on reading material	Small groups of students review questions
5	Class discussion; assign reading (6B-3; 6A-8 through 6A-14)	Discuss reading questions	---------	------------
6	Discuss reading	---------	---------	-----------

phase and the Expanding the Idea (E) phase. The Invention (I) phase was a teacher-led class discussion. In one of the test groups (Teacher 1) the teacher presented and explained arrays of previously collected data in the G and E phases. In the test group called "Teacher 2", the teacher performed demonstrations to generate data in the G and E phases. The I phase for each of these groups was a lecture by the teacher on the concept. The third test group, labeled as the Reading group, utilized written material for all three phases of the learning cycle. This information is summarized in Table 6-3.

The student materials and teacher's guide materials are included in Appendices 6A and 6B, respectively. Table 6-4 summarized the daily activities of the groups involved in this test. Appendix page numbers referring to curriculum materials are given in parentheses.

Post Investigation Discussion

As has been the case in past learning cycles the two instructors and the principle investigator had a discussion after Learning Cycle 7 in order to compare observations of classroom lessons and to share feelings and antidoes about the instruction during the learning cycle.

The instructor who taught class 11, which was a teacher control lecture, expressed frustration over teaching this group. "My first block was the lecture group. When I gave the lecture during the invention phase, they virtually forced all their questions into laboratory format. 'What color was it and what did it look like? 'Did it produce a gas?' These are the sorts of questions they asked. Things that if they had been in a laboratory they would have literally seen for themselves. They literally tried to gather the data without actually seeing any equipment or working with it." The observer of that particular class said that he noticed that they used past experience that they had had in junior high school and one actually said, "We did that one didn't we in junior high school? That was the one that had the yellow paint experiment or something."

(This reference concerned the lead iodide which was used as chemical in this learning cycle.)

The teacher of this group indicated that eventually the students adjusted and, "After they saw a pattern developing, that I was going to talk and they were going to take notes, then they did pretty well and settled down and just did it." On their evaluations, however, a good share of them indicated that if they could have done the laboratory, it would have helped.

The teacher who taught section 16, which was the lesson controlled by reading, said, "As far as I'm concerned, it was a total loss. They got the reading, they read it in class, and then I asked if they had any questions. They just didn't know enough about it to ask questions or care without the laboratory or teacher directions. They had just given up trying to understand the material at all." This instructor indicated that he thought that students really are not very good readers. The impression he gets is that you cannot depend on them to get very much useful information out of reading. "These students are mostly used to reading for amusement but are not very good about getting technical information out of reading. Their major response to the readings is that they were boring. We haven't stressed technical reading enough in the schools," he said.

Another point that was raised during this discussion came up when students in the reading group were asked to fill out the BAR evaluation on this learning cycle. Several students indicated that they did not have a good perception concerning when the learning cycle began. The indication here was that these students didn't have an awareness of the structure of the lesson.

Both teachers indicated that in the classes where no laboratory work was done, there was a certain lack. In class 25, where a demonstration was done instead of the laboratory, the instructor indicated that their students indicated a desire for laboratory work. The demonstration did not seem to substitute for the laboratory. They didn't think that the demonstration took place of the laboratory. One of the girls in this class wrote on the back of her BAR evaluation that "everything was O.K., but I sure would like to break out and do something different once in a while." When the teacher read that, he asked her what she meant, and she said, "I would like to do a laboratory." In this teachers words, "These students all have cabin fever. They'd like to break out of their formal classroom and into a laboratory environment." The other instructor also indicated similar comments on the backs of the BAR evaluations in her class. According to her however, "Most of the comments on the backs of the papers were not, "I want to do a laboratory"--they were more like, "I feel that if I did the laboratory, I would remember the reaction better, I would have more evidence to come to conclusions." Both instructors said that their classes which went through the learning cycle as normally written (both control groups and those groups which were not involved in the experiment itself) had, in their opinion, no difficulties.

From an academic rather than an attitude point of view, the instructor who taught section 25, where demonstrations were done, felt that this class related pretty well to the data that was gathered in the demonstration even though they didn't collect it themselves. According to him, these students kept referring back to the data collected during the demonstration several times. "They would mention the lead nitrate and the potassium iodide and they would say, 'Yeah, you get a yellow precipitate when you added those together.'"

This discussion was followed by a discussion concerning the retention examination which will be given six weeks after the end of this experiment. The point was made that chemistry, as taught in this course, did not consist of discrete concepts. Because of the constant building from one concept to another, there is bound to be some interactions between what they've learned or perhaps not learned very well in this learning cycle, and concepts in future learning cycles. The point was made that perhaps a retention test would not be a judgment of what they learned in this learning cycle so much as what they learned in this learning cycle plus all the future material that they are exposed to before the retention test is given.

Another point that was brought up in the discussion was the difficulty of this particular concept for some students. Although the students seem to be able to talk about chemical reactions in terms of observable information and weight loss, they had difficulty with relating chemical reactions in terms of atoms, molecules, and the interaction between them. Many of the students didn't learn that a chemical reaction is thoughtof in terms of the molecular level. They would go back to previous information about physical versus chemical change, using reversible and non-reversible kinds of arguments, but they did not refer to rearrangement of atoms.

A few of the students have identified chemical reaction in terms of rearrangement of ion groups; however, as in ion exchange reactions. One of the case studies, for example, indicated that he thought that a chemical reaction involved the rearrangement of ions. When challenged with the idea of the synthesis reaction between magnesium and oxygen, he indicated that this did not apply to the rule for a chemical reaction involving exchange of ions, and he realized that there was a problem with focussing on just ions. Nevertheless, he was unable to come up with the key of the interaction and rearrangement of atoms and molecules.

The final point made during this discussion was that students seem to be able to develop the skills of writing and balancing chemical equations, but for many students these materials are just symbols and numbers that they are manipulating with certain rules in mind. Understanding the concepts underlying the writing and balancing of equations was tenuous.

Case Studies

One student from each of the four classes involved in learning cycle 7 was chosen as a case study for in-dept interviews. Each of these students was interviewed four times during Learning Cycle 7, once as a pre-test and once after each of the three phases of the learning cycle (gathering data, invention and expansion). Although the students who were involved as case studies were not necessarily representative of their particular groups, these case studies did often result in data which when used with the other observational and statistical data, helped to interpret and understand the effect of the various treatments used during the experiment. Following are detailed reports on each of these four case studies.

Case Study 17. The teacher described this case study as a very quiet and uninvolved student. He would not take part in a class discussion unless he was called on to answer a question. During his pre-learning cycle interview he expressed his opinion that taking notes was a more valuable way to study science than doing laboratory work. The case study was very concerned and nervous during the interviews that he would "mess up" his answer. A profile of CS-17 is found in Table 6-5.

This case study was in Class 11. For this Lesson Control Experiment the class was the T_1 (teacher) group. This means that the teacher was in control of each of the lessons. During the gathering data phase of the learning cycle the method of collecting the data was described to the students and the data was given to the students in table form. In invention phase was done as lecture. The expansion phase consisted of two parts: the first part consisted of the description of a laboratory and the data being presented in table form and the second part was a lecture over the reading material and a set of questions. There were four interviews scheduled with this case study: a pre-learning cycle, post-gathering data, post-invention, and post-expansion. These interviews will be designated by pre-LC, post-G, post-I, and post-E respectively.

The central concept of Learning Cycle 7 was that chemical reactions involve changes in the combinations of atoms. The case study was asked to express his idea on the following topics: (1) What happens during a chemical reaction?

TABLE 6-5

CASE STUDY PROFILE

Student	17			
Sex	M			
Class	11			
Grade Level	11th			
Birthday	06-25-65			
I.Q.	-			
GEFT[1]	-	(Quartile -)		
VH[2]	3			
FR[3]		6		
CC[4]		6		
Grades[5]	B	B	C.	B

Variable Lesson Control

Group T_1 (Lecture)

LC 7 test scores (unadjusted)

CAT 1 0%

CAT 2 86%

CAT 3 76%

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

(2) Given a set of reactants, predict the products and (3) Why do we balance equations?

During the pre-LC interview the case study had misconceptions concerning the nature of chemical reactions. He seemed to confuse the writing of a formula for a compound with the equation for a chemical reaction. For a given chemical reaction, if he could not account for all the reactants, he thought they went off as a gas.

For the purpose of using excerpts from the interview audio tapes, I will designate the questions or comments by the interviewer and CS will designate the responses given by the case study.

The following are quotations from the case study's pre-LC interview tape which should illustrate the foregoing summary.

I: Can you describe what happens when a chemical reaction occurs?

CS: Two atoms combine--become two ions, let's see how can I, chemical reaction...

I: Can you give me an example of a chemical reaction.

CS: Salt would be one. Two chemicals combine to make salt. That would be a chemical reaction, wouldn't it? What combines to make salt would be a chemical reaction, right?

I: I'm not sure, what you are saying.

CS: On chemistry, I'm not that good.

I: Can you give me an example of chemical reactions you have done this semester or one you are familiar from another source?

CS: My mind draws a blank. I can't think of anything right now.

I: Would the burning of magnesium be a chemical reaction?

CS: Yes, that would be a chemical reaction.

I: Could you give me an equation for that chemical reaction?

CS: We combined water with the magnesium. No first, we heated it and then added the water. I can't remember what chemical it made up.

I: Do you know the symbol for magnesium?

CS: Mg.

I: What might that combine with if you heated it?

CS: Oxygen...It formed magnesium oxide.

I: What's the formula for that?

CS: MgO_2, no.

I: Does it make any difference what the formula is?

CS: A certain number of atoms have to combine together. I just can't explain why.

I: The formula for magnesium oxide is MgO. Can you write an equation to indicate what that reaction is forming?

CS: $Mg + H\uparrow_2O \rightarrow H_2O$.

I: Why do you have the arrow?

CS: The hydrogen atom in the water just wouldn't combine with any so it just floated away, turned into a gas.

During the pre-LC interview the case study was asked to predict the products which would form from a set of reactants. From the responses the case study gave it is obvious that he has no idea what the products would be.

I: I'll give you the reactants of a chemical reaction you have not seen before. Can you predict what the products would be?

CS: Sure, I'll try.

I: $AgNO_3 + Na_2CrO_4$ are the reactants. Give me your best prediction of what the products would be.

CS: Sodium nitrate...I don't know what else. This just really baffles me. Let's see, you might get silver? Chrome nitrate--I'm just taking a guess. Chrome and one of the parts would be oxygen.

I: What strategy are you using?

CS: Oxygen might burn off and there's silver in there.

There was not an audio tape of the post-G interview with this case study. however, the interviewer did take notes during the interview. The notes taken indicate the case study was still confusing chemical reactions with the writing of formulas. The case study was trying to use information from Investigation 6, "The Atom", to develop charges on ions.

During the post-I interview the case study indicated that he had not assimilated the information presented to the class. The lectures had little effect on him. However, he was beginning to use some reasoning to predict the products of the chemical reaction and to write the equation. For instance, he indicated that elements had to be present for the products to form.

I: Since we talked last time in class, you had a discussion. Do you recall what that discussion was about?

CS: No, I don't know what that day's discussion was about.

I: The teacher presented some data about reactions, some of which formed precipitates and some that didn't. Does that sound familiar?

CS: No, it doesn't. I'm not sure about this precipitate stuff. I haven't memorized it.

I: What did you do today?

CS: Our assignment was how to write out a formula. Of course, we have the assignment to predict the products and write out the equation.

I: Have you done some of those?

CS: I've done three or four. I think I have it down pat.

I: Did you do copper plus nitric acid?

CS: Yes.

I: Why don't you just talk your way through that one? Tell me how you reasoned.

CS: She had copper, CU and...

I: Nitric acid, HNO_3, and it produced a blue solution and a brown choking gas. What was the brown choking gas?

CS: The brown choking gas, I forgot what it was, she had it on the papers. (student was handed a copy of the chart--see Appendix 6-A). Here it is. It would have to be nitrogen dioxide because bromine, there's not elements for bromine in it, so bromine couldn't be formed. So, I put down nitrogen dioxide would form, NO_2. You have left over copper, one molecule of oxygen and one molecule of hydrogen. I mean one ion of both. So you get NO_2OH, I'm not sure what I forms. Oh, you would have $NO_2 + CuOH$. When copper combined with nitric acid you had formed $NO_2 +$ $CuOH$ because you had copper, oxygen, and hydrogen left after the brown gas was formed.

I: Is that balanced?

CS: Yes, I think it's balanced.

I: I want you to try this one. Lead metal, Pb, reacts with sulfuric acid, H_2SO_4, to produce a white solid precipitate and suffocating, choking gas. You can look at your gas list. (See Appendix 6A).

CS: (Looking at chart of gases) That might be it, Sulfur dioxide, SO_4. Cl_2 gas couldn't be it because there isn't any chlorine in it. Br_2 couldn't be it because there's no bromine in it. It couldn't be NO_2 because there's no nitrogen. There is oxygen. So, I'd say the gas is sulfur dioxide.

The case study asks about charges but finally gave up working out all the products of that chemical reactions.

The final interview, post-E, with this case study revealed a student whose confidence level surpassed his knowledge of the material. He has developed some terminology but often confuses how to use it. The case study has good observational methods for determining if something is a chemical reaction but his theoritical reasoning is poor. He repeats a misconception that hydrogen even in a compound is neutral.

I: What is a chemical reaction and what happens during a chemical reaction?

CS: It's a combining of negative and positive ions. It must be balanced out. A new substance can be formed that has different properties that cannot be changed back by physical means to original properties.

I: Let's write a reaction between sulfuric acid, H_2SO_4, and barium nitrate, $Ba(NO_3)2$.

CS: Sulfuric acid is the first one. I'm still a little confused about how hydrogen goes in with sulfate since it is not positive or negative. (pause... he asks for the charges on some of the ions). I don't know how to balance this one out.

I: What do you need to know?

CS: The hydrogen is neutral so I don't know how or if it would combine with the nitrate.

I: Why do you think the hydrogen is neutral?

CS: It can't form an ion because it only has one electron.

I: Why can't it form an ion?

CS: Oh.

I: How do you form an ion?

CS: By adding or taking away of electrons.

I: Does hydrogen have an electron?

CS: Yes, I think it has one.

I: Could it lose that one?

CS: Yes, but...

I: If it did, what would it be?

CS: I don't know.

I: So, you have written $H_2SO_4 + BaSO_4 \rightarrow BaSO_4 + H_2NO_3$.

CS: I'm not sure about the H_2NO_3. It would balance out because the sulfate has two more electrons and the barium has two more protons than normal. It would balance because that would give you the right number of each.

I: Would you give me your reaction to your classes in this investigation?

CS: The first time she give us the information it's kind of confusing but she'll give us a sheet to work on and then the second day I'll understand it better. I think I got all the questions right on that last sheet.

I: A lot of students were complaining about not having laboratory materials.

CS: Oh, I don't mind taking notes. Some people just don't like taking notes. They would rather do a lab.

I: Do you think it would have been clearer to you if you had done a lab?

CS: It was clear to me. I understand notes just as well as a lab.

In summary, this case study was missing quite a bit of background information which made the concept for learning cycle 7 even more difficult for him. As stated earlier one of the problems with this was that he was over confident of his understanding of the material. His misconception of a chemical reaction being the same as the writing of a formula for a compound seemed to persist through the entire investigation. There was very little evidence that the lectures given in class helped the case study's understanding of the concept.

Case Study 42. The teacher described this case study as an involved, intelligent student. He was serious in his studies and yet liked to be distracted. Although the case study was of foreign nationality and had been in the United States only two years, language was not the barrier to him that one might have thought it would be. His plans for the future are to attend medical school in the Eastern United States, and he realized that the chemistry he learned now would help him at a later date. A profile of CS-42 is found in Table 6-6.

The case study was in class 16 which for this Lesson Control Experiment was the Reading Group. This means for this learning cycle each phase--gathering data, invention and expansion--was done by the students reading the material. Each reading was done during class time and was followed by a discussion. There were five interviews scheduled with this case study: (1) pre-learning cycle, (2) post-gathering data, (3) post-invention, (4) post-expansion laboratory, and (5) post-expansion reading interview. These interviews will be designated by (1) pre-LC, (2) post-G, (3) post-I, (4) post-E_1, and (5) post-E_2, respectively. The post-I interview was not held due to a scheduling conflict.

The central concept of learning cycle 7 was that chemical reactions involve changes in the combinations of atoms. During each interview the case study was

TABLE 6-6

CASE STUDY PROFILE

Student	42			Variable	Lesson Control
Sex	M			Group	R
Class	16			LC 7	test scores (unadjusted)
Grade Level	11th				
Birthday	11-19-65			CAT 1	33%
I.Q.	100			CAT 2	76%
GEFT[1]	10	(Quartile 2)		CAT 3	90%
VH[2]	3				
FR[3]	6	4			
CC[4]	5	3			
Grades[5]	A	A	A		A

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

asked questions about the following topics: (1) What is your definition of a chemical reaction? What happens during a chemical reaction? (2) The student was given some reactants and asked to predict the production, and (3) The case study was asked to balance the equations and why the equation should be balanced.

During the pre-LC interview, this case study illustrated that he had an operational definition of a chemical reaction. He as able to give an example of a chemical reaction, however, when he was given a set of reactants, he could only guess at the possible products. Quotations from audio tapes of the interviews will be used to illustrate the student's ideas before the learning cycle. I will be used to designate questions asked by the interviewer and CS will be used to show responses given by the case study.

I: What's involved in a chemical change?

CS: For example, if two substances involved; after reaction is over, those two reactants are not the same as they were before. They are changed chemically--the way the atoms are arranged has changed. Maybe the form has changed--phases.

I: Could you write down an equation for a chemical reaction?

CS: $NA + Cl \rightarrow NaCl$.

I: Is this an example of a chemical change?

CS: Yes.

I: Given some reactants, $Al_2(SO_4)3 + Ba_3(PO_4)2$, I would like for you to predict what would form as a result of those reactants combining.

CS: (pause) $Al_2(PO_4)_2 + Ba_3(SO_4)_3$.

I: Is that balanced?

CS: I guess it is.

I: Why did you choose those combinations?

CS: I really don't know.

I: You didn't pick Al with Ba. Is there any special reason you didn't combine them?

CS: Because, I just didn't do it.

The case study was rising the subscripts of the ions in the reactants also in the products as a way to balance the equation. He knew that the equation should be balanced although he was confused about how it should be done.

During the post-G interview the case study revealed an interesting misconception dealing with the use of subscripts in a formula to balance an equation. The interviewer began the interview by reminding the case study of the reactants they had discussed in the previous interview.

I: Last time we talked about the chemical change between $Al_2(SO_4)_3 + Ba_3(PO_4)2$. Would you write those down? Would you write the products for this reaction?

CS: $AlPO_4 + BaSO_4$.

I: Is that a correct equation the way you have it written?

CS: I really don't know. I thought PO_4 taken twice and Al has 2 as a subscript so they cancel each other out. Also, Ba is taken 3 times and SO_4 is taken 3 times so they cancel each other out. That's why they have a 1 down here.

There were two interviews held in connection with the expansion. Post-E refers to the interview after the reading which covered what would normally be a laboratory exercise. Post-E_2 was the interview conducted following the final reading of the learning cycle. During the post-E_1 interview the case study was asked to work on the equations for the same chemical reaction he had been working on in the two previous interviews. He was able to write the equation correctly with some information about the change of the ions involved being given to him.

I: We've been talking about a chemical change between $Ba_3(PO_4)_2 + Al_2(SO_4)_3$. Would you predict the products?

CS: Is SO_4 a positive or negative ion?

I: It's negative.

CS: And Ba is positive?

I: Yes. In fact, let me give you some more information, Ba^{2+}, Al^{3+}, SO_4^{2-}, and PO_4^{3-}.

CS: $AlPO_4 + BaSO_4$.

I: This is what you have--$BA_3(PO_4)_2 + Al_2(SO_4)_3 \rightarrow AlPO_4 + BaSO_4$--is that an equation?

CS: Yes, it looks like it--2 and 2 reactants. I'm not sure if it's balanced.

I: Is it necessary that it be balanced?

CS: Yes.

I: Why don't you check and see if it is balanced?

CS: By balanced you mean the products must be equal to the reactants?

I: Is that what you mean by balanced?

CS: The number of molecules must be equal.

I: When you say an equation is balanced what are you saying?

CS: The amount of molecules or the amount of matter we used as the reactants we have to get the same amount on the other side of the equation.

I: The same number of molecules?

CS: Yes.

I: Now do you have the same number of Al on this side as on the other side?

CS: Will we have 2Al here, no, I don't have the same number.

I: You wrote 2AlPO4 + 3BaSO4. Why did you do that?

CS: When you put 2 in front of the whole thing it means 2 of both things--2 of Al and 2 of PO4; and when you put 3 in front of BaSO4, it means 3Ba and 3SO4. I mean ions rather than molecules.

I: You originally put Al_2PO_4 and then you crossed out the subscript 2. Would you explain why you did that?

Cs: Al is +3 and PO4 is -3 and a +3 and -3 would make it neutral. Compounds must be neutral.

The case study expressed during the post-E_2 interview that the final reading had helped him to predict products and write the formulas. He said he was able to balance the equations on the question sheet which followed the reading.

In summary, the case study did not seem to progress in his ideas of the central concept during the gathering data phase. During the invention phase and/or the expansion phase of the learning cycle, there was a gain in the case study's ability to work with writing correct formulas, balancing equations and the ability to predict products. The learning cycle that this case study had followed did not contain any laboratory exercises. The case study did not seem to be bothered by this because he felt the laboratory experiences would come at a later date.

Case Study 102. This case study was described by her teacher as being reserved in her demeanor in class discussions but willing to answer questions posed directly to her. She was a capable student and her performance was steady throughout the year even though she had significant demands placed on her time by her participation in athletics. She never seemed to be in a hurry. In fact, during the case study interviews, she would frequently pause for almost a full minute before responding to a question. A profile of CS-102 is found in Table 6-7.

Learning cycle 7 was a lesson control form experiment in which this case study's section participated as the control group. In this section, therefore, students performed all three phases of the learning cycle in order (G, I, and E) and they utilized the materials as written. The student laboratory and reading materials were included in Appendix 6A.

Five interviews were conducted with this case study. They are labeled as pre-LC, post-G, post-I, post-E_1 and post-E_2. The post-E_1 interview was conducted between the E phase laboratory activity and the reading and post-E_2 interview occurred after the reading.

In the pre-LC interview the case study had good memory of previous laboratory work. Her definition of chemical reactions was an observationally based one carried over from learning cycle 2. She made no attempt to explain chemical reactions with any theoretical model and she was not able to predict products of a reaction when given the reactants. It can be noted that her definition for a chemical reaction implies a synthesis type of reaction. I stands for interviewer and CS stands for case study in the dialogue sections.

I: What is your idea about what a chemical reaction is?

CS: When two elements go together to form something else. They both change and have totally different characteristics.

I: What happens when materials react chemically?

CS: Color changes, odors...it can't be changed back.

I: Why can't you change it back?

CS: I don't know.

I: Can you give me an example of a chemical reaction?

CS: When magnesium reacted with air it formed magnesium oxide.

I: Can you write an equation for that?

CS: $Mg + O_2 \rightarrow MgO$.

I: What happens to the Mg and the O to allow it to make MgO?

CS: I don't know.

I: If I were to give you an example of reactants in a chemical change, could you predict the products? (The interviewer wrote: $AgNO_3 + Na_2CrO_4$, and named the substances.)

CS: I've drawn a blank on this.

The post-G interview revealed that the case study maintained the same definition as before for chemical reaction. She was still unable to predict products of a chemical reaction and her evidences for chemical reaction were still observationally based.

TABLE 6-7

CASE STUDY PROFILE

Student 102

Sex F

Class 22

Grade Level 11th

Birthday 02-28-65

I.Q. 120

GEFT[1] 11 (Quartile 2)

VH[2] -

FR[3] 4 4

CC[4] 5 5

Grades[5] A A A A

Variable Lesson Control

Group Control

LC 7 test scores (unadjusted)

CAT 1 0%

CAT 2 86%

CAT 3 86%

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

The case study was still not prepared to discuss a theoretical model for chemical reactions in the post-I interview. Her definition for chemical reaction remained the same as in the pre-LC interview. In the course of talking with the interviewer about the reaction that had been done during the G phase, the case study was able to write a correctly balanced equation for the reaction.

The post-E interview focused on the laboratory work that had been done in the E phase of the learning cycle. No class discussion of this activity had occurred at the time of the interview. The case study was experiencing some disequilibration with the prediction of products of chemical reactions.

I: Did you have a chance to write equations?

CS: I can't do that! When he does it on the board, I can understand what he's doing, when he's balancing it, but I can't do it when I have to predict the products.

I: So, you didn't have too much success writing the reactions yet?

CS: No, I know that the substances had a chemical reaction--I got that far--but I don't know how to write the possible results of the reaction.

I: You said you had four reactions. Do you think that you have four different precipitates?

CS: I don't know.

The case study made her first attempt to state a theoretical definition of a chemical reaction during the post-E_2 interview. The reading had provided a means for various types of chemical reactions which the case study had not completely organized prior to the interview. There was interesting interaction with the case study about the definition she gave during this interview as it related to reactions that did not involve exchanges of ions. The case study still showed signs of being disequilibarated but her disequilibrium was shifted to the problem of developing an umbrella definition for chemical reaction.

I: Describe what you have learned in the discussion of the reading.

CS: We worked at balancing equations and talked about double displacement, single displacement, synthesis, decomposition. When you asked about what was going on in a chemical reaction (referring to previous interviews), it was that the ions are changing partners to form different combinations of different substances.

NOTE: This definition would have the laboratory work of this learning cycle as its basis.

I: What is a synthesis reaction? Can you give me an example?

COMMENT: The case study confused synthesis with decomposition in her example and the interviewer pointed out the distinction between the two to her. The interviewer then talked through the experiment in which hydrated copper (II) sulfate had been heated, stopping short of writing a balanced equation for the reaction.

CS: This is decomposition, right?

I: Is it balanced?

CS: No. This is the fun part. (She then proceeded to write down the balancing coefficient.)

I: According to your definition, what ions changed places?

CS: None probably did.

I: Is it a chemical reaction?

CS: Yes, because color changed, texture changed. The only thing that changed was the colors. I don't know.

I: What is the difference between a chemical and a physical change?

CS: A physical change you can reverse.

I: Can you reverse this?

CS: Put water back in.

I: Can you write an equation for the reaction of magnesium and oxygen? What kind of reaction is that?

CS: Chemical reaction, I think, because you had two different substances to make one, and it has different properties... (long pause) synthesis reaction.

I: Does your definition about ions changing places fit?

CS: No.

I: Can you give an example of a chemical reaction where ions are exchanged?

CS: When lead nitrate reacts with potassium iodide to produce lead iodide and potassium nitrate.

I: Can you tell me what happens when these other types of chemical reactions occur?

CS: I don't think there's just one thing you can say about them all to define a chemical reaction. I don't know how you could say it in a simple statement.

The case study did not show much evidence of having her content structures tested in this learning cycle until the E phase of the learning cycle. The questions following the E laboratory, which asked for prediction of reaction products, seemed to cue the case study to the need for adjusting her structure relating to chemical changes.

Case Study 116. The experiment in LC-7 was a lesson control experiment. The section of which this student was a member, moved through the learning cycle by having the teacher demonstration experiment in the G phase, a lecture in the I phase, another demonstration experiment performed by the teacher in the E phase and finally a lecture over the content of a reading. The student materials for this learning cycle, before the modifications necessitated by the lesson control experiment, can be found in Appendix 6A. A profile of CS-116 is found in Table 6-8.

Four interviews were conducted with this case study in the process of the test. There was one interview prior to the beginning of the test (pre-LC) and then one interview was held after each phase of the learning cycle (post-G, post-I, and post-E). The central concept of the learning cycle was that chemical reactions involve changes in the combinations of atoms. In addition to this concept, the case study was asked to predict products of chemical reactions,

TABLE 6-8

CASE STUDY PROFILE

Student	116		Variable	Lesson Control
Sex	F		Group	T_2
Class	25		LC 7	test scores (unadjusted)
Grade Level	12th			
Birthday	01-04-64		CAT 1	33%
I.Q.	102		CAT 2	76%
GEFT[1]	11	(Quartile 2)	CAT 3	86%
VH[2]	3			
FR[3]	3	4		
CC[4]	4	5		
Grades[5]	B	B	D	C

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

when given reactants, and to balance chemical equations.

The case study's initial statement to define a chemical reaction suggested that she did not have a clear understanding of this concept. She was unable to write reasonable products for sets of reactants generated during the interview. In the following sequence I stands for interviewer and CS stands for case study.

I: What is meant by the term chemical reaction?

CS: A reaction that happens when you change chemicals.

I: Can you give me an example of a chemical reaction?

CS: Magnesium when you add water to it.

I: Can you write an equation for that? (The case study wrote: $Mg + H_2O$ and she was unable to expand on that.)

I: If you were given the reactants $Al + HCl$, what would be produced by their reaction? (The case study wrote: $AlHCl$.)

During the post-G interview the case study had memorized the common ions sufficiently to be able to use them in writing correct formulas for compounds. Predicting products of a reaction seemed to be a matter of putting all the reactants together into one lump. The case study's misconception about the nature of chemical change relates to her method of predicting products and also to a scheme of mixing two substances to make a formula that is itself the chemical change. At this point in the learning cycle, the case study also had misconceptions regarding the formation of precipitates.

I: When your teacher mixed lead nitrate with potassium iodide, did a chemical reaction occur?

CS: Yes.

I: What was your evidence for that?

CS: There was a color change and a texture change. There was a precipitate.

I: Can you write an equation for the reaction?

CS: (With help from the interviewer in getting correct formulas for the reactants, the case study wrote: $Pb(NO_3)_2 + KI \rightarrow Pb(NO_3)_2KI$).

I: Is one or both of those substances produced going to be insoluble in water?

CS: I don't know.

I: Could PbK be one of your products?

CS: Was that what he mixed yesterday? (pointing to formulas for lead nitrate and potassium iodide)

I: Yes.

CS: Yes, it could.

I: What charge ion does lead form?

CS: Lead has a positive.

I: And what charge does potassium ion form?

CS: Potassium has a positive, too, so it couldn't be because they would repel each other.

I: Can you give me another example of an equation for a chemical reaction?

CS: (wrote down the formula PbI_2).

I: What would you mix together to get lead iodide?

CS: Lead and iodide.

I: When lead nitrate and potassium iodide are reacted, there is a residue and a filtrate produced. Which of two substances (equation is written in front of the case study) is the residue?

CS: Lead iodide.

I: Why did you say that?

CS: Because the filtrate was the one that filtered out and the residue would weigh more.

Following the invention lexture (post-I), the case study seemed to have a better grasp of the need for differentiating the products of a double displacement reaction (although she did not use the terminology), but she showed a lack of understanding of the reasons for balancing an equation and of the procedure involved in getting an equation balanced. Evidences listed for a chemical change are restricted to observational evidences from the experimental system. There seems to be no theoretical model for the phenomenon.

I: Can you give me the evidence you have for a chemical reaction when lead nitrate and potassium iodide are mixed?

CS: Color change, texture change, and a precipitate.

I: Can you write a chemical equation for that reaction?

CS: (The case study wrote correct formulas for reactants and products.)

I: Have you accounted for all the kinds of atoms and the number of atoms in that equation?

CS: (The case study saw the need to add coefficients but she was not able to complete the balancing process.)

I: Why do we need to add coefficients when we write a chemical equation. Why does it need to be balanced?

CS: I'm not sure.

During the post-E interview the case study's idea of a chemical reaction did not seem to have changed much in the course of the learning cycle. The hint of a somewhat deeper understanding is given in the addition of the idea of "producing another chemical". She had, by this interview, developed a partial understanding for the need to balance equations (same number of atoms on both sides). Furthermore, she was able to balance a chemical relationship given to her by the interviewer.

I: Would you describe a chemical reaction?

CS: When two different chemicals are mixed to form another chemical.

I: What actually happens when they form this other chemical?

CS: They mix and produce another chemical.

I: Why do you balance an equation?

CS: So that the same number of elements are on each side.

I: Let me give you an equation and I'd like for you to balance it for me. (The interviewer wrote: $Al + HCl \rightarrow AlCl_3 + H_2$. The case study then added coefficients to propertly balance the equation.)

I: If aluminum is put in hydrochloric acid it produced aluminum chloride and hydrogen. That is a chemical change. Can you tell me what happened in that chemical reaction?

CS: Well, the positive aluminum went together with chloride to form a neutral formula and you have hydrogen left over so the hydrogen goes off.

These interviews suggest that the case study could not see clear connections among the various content in the learning cycle. She seemed to deal with each question in isolation and on a concrete level. In the final interview, however, the case study hinted at the combination of ions to form aluminum chloride. That she treated hydrogen gas as being "left over" in that reaction may have been an attempt to make the reaction fit her definition of two chemicals mixing to form another chemical.

In summary, the case study neither totally assimilated nor accommodated to the main conceptual content of the learning cycle. She discussed ions from time to time but she did not show evidence that she understood the ion rearrangement or exchange idea in the double displacement reaction.

Summary. The most interesting results from these case studies concern CS-17 who was in class 11, which had the lecture format. Although CS-17 indicated a preference for note taking over laboratory experience, he did not seem to gain as much as he seemed to think he did from the lecture itself. Occasionally during the year of investigation of the use of laboratory material in high school chemistry there was a small group of students who would constantly indicate that they would like to get directly to the point and not waste so much time by doing laboratory work and having discussions. These students seem to prefer to have the teacher tell them through lectures or other formats what it is that they needed to know so that they could then learn it in the most efficient and fastest manner possible. If this student is any indication, students with this attitude are, at least in part fooling themselves.

Subject 102, who was in the control group (class 22), gave evidence that the expansion phase was the place at which the subject was able to "put it all together." This is similar to results that have been seen in other learning cycles and leads one to suspect that the necessity of the expansion phase is much more important than was previously hypothesized. Two possible explanations for this are: (1) That students during the earlier phases of the learning cycle might be disequilibrated and that the exploration phase is the point at which this equilibrium is able to take place; and (2) Organization takes place during the exploration phase. Perhaps until the student is able to "put thought in accord with other thoughts" full understanding and the implications of a concept are not possible. This might be evidence, albeit thin, for the idea that organization takes place during the expansion phase of the learning cycle.

Achievement Analysis

Two versions of the cognitive achievement tests were utilized in assessing the content achievement of the students in the Learning Cycle 7. These two versions were not designed to be equivalent. The A version was used as a pretest and was designed only to test whether students had any significant knowledge of the concept being taught and secondly, whether the classes were equivalent to each other. The samples of the two versions of the Cognitive Achievement Test can be found in Appendix 6C. Also, in Appendix 6C can be found the grading criteria for each of the two versions of the exam. The B form of the test was used as both a post-test and as a retention test which was administered six weeks after the end of the lessons associated with Learning Cycle 7.

TABLE 6-9: LC-7: SIMPLE CHEMICAL REACTIONS

ANOVA for CAT 1 (Pretest) vs. Class

Source of Variation	DF	Mean Square	F	P	
Class	3	1092	3.81	0.01	*
Error	86	286			

Summary of Means

Class	CAT 1
11	27.5
16	27.5
22	21.2
25	37.6

TABLE 6-10: LC-7: SIMPLE CHEMICAL REACTIONS
ANCOVA for CAT 2 (post test), Class vs. Developmental Level
Using Pretest As Covariate

Source of Variance	DF	Mean Square	F	P	
CAT 1	1	513	3.30	0.07	*
Class	3	201	1.29	0.28	
Developmental Level	1	386	3.49	0.11	
Class X Level	3	161	1.03	0.38	
Error	78	155			

TABLE 6-11: LC-7: SIMPLE CHEMICAL REACTIONS
ANOVA for CAT 2 (post test), Class vs. Developmental Level

Source of Variance	DF	Mean Square	F	P
Class	3	113	0.67	0.57
Developmental Level	1	124	0.74	0.39
Class X Level	3	313	1.87	0.14
Error	88	167		

Table 6-9 summarizes the analysis of variance for the pre-test scores by class. Two facts can be seen from this analysis of variance. First of all, the classes are not equivalent to each other with respect to their pre-test scores. The second fact is that all of the scores even though they're not equivalent are relatively low. This ambiguous information leaves us with the dilemma as to the data analysis of the remaining CAT scores. It was decided to do two analysis. One, an analysis of covariance using the pre-test scores as a covariant, and the other to do a straight analysis of variance ignoring the pre-test scores and assuming equivalence of knowledge by all of the four experimental groups. As will be seen, the analysis of the data is not much different using either of the approaches. Table 6-10 has the analysis of covariance for the post-test scores, class versus developmental levels, using the pre-test as a covariant. As can be seen from this summary, the covariant is significant. However, the remainder of the tests indicate no effects; either main effects involving class or developmental level or interaction between class and developmental level. The analysis of variance without the covariant gives similar results. In summary, there's no evidence that the form of the learning cycle in this experiment affected the amount of knowledge gained by the students from the lesson in the short term.

It was decided, however, to assess the retention of this information over a period of time (six weeks). Table 6-12 and 6-13 summarize the analysis of covariance and the analysis of variance for the retention test, class versus developmental level. Once again the analysis of covariance use the pre-test as a covariant. In both of these cases, there is a main effect for developmental level and an interaction effect between class and developmental level. Comparing the differences between these means using the Newman-Keuls has the following results. Formal students in class 25 score significantly higher than concrete students in class 25 and formal students in class 16 score significantly

TABLE 6-12: LC-7: SIMPLE CHEMICAL REACTIONS
ANCOVA for CAT 3 (Retention test), Class vs. Developmental Level
Using Pretest as Covariate

Source of Variance	DF	Mean Square	F	P
CAT 1	1	187	1.96	0.17
Class	3	62	0.35	0.79
Developmental Level	1	596	6.22	0.02 *
Class X Level	3	311	3.24	0.03 *
Error	66	96		

Least Square Means

Class	Concrete	Formal
11	79.1	83.0
16	72.3	87.2
22	79.8	75.1
25	73.9	83.1

Summary of NK ($\alpha = .1$)		
concrete 22	>	concrete 16
formal 16	>	formal 22
formal 16	>	concrete 16
formal 25	>	concrete 25

TABLE 6-13: LC-7: SIMPLE CHEMICAL REACTIONS

ANOVA for CAT 3 (Retention Test), Class vs. Developmental Level

Source of Variance	DF	Mean Square	F	P	
Class	3	26	0.16	0.92	
Developmental Level	1	959	6.01	0.02	*
Class X Level	3	443	2.61	0.06	*
Error	82	160			

Least Square Means

Class	Concrete	Formal
11	75.5	79.1
16	72.4	86.5
22	79.3	74.7
25	71.1	85.8

Summary of NK ($\alpha = .1$)

concrete 22 > concrete 25

formal 16 > formal 22

formal 16 > concrete 16

formal 25 > concrete 25

higher than concrete students in class 16. Since class 16 was a reading group, it is no surprise that formal operational students are able to retain more from reading information that concrete operational students can. Less easily explained perhaps is a similar pattern with the demonstration. As a corollary to this, it doesn't seem to make very much difference between formal and concrete students in terms of the retention of lesson information if they are taught via lecture or the control group which was a laboratory/discussion.

It can also be seen from both analyses that the formal students in class 16, which was the reading group, scored better than the formal group in class 22, which was the control group with the laboratory discussion format. Of course, formal operational students are better able to take advantage of readings and there is a question of an interaction between this information and information in following learning cycles. Formal operational students who have readings might be able to take advantage of a concise summary of the information to a greater extent than the formal students who had not gotten such a concise summary as would be the case in the laboratory.

The two analyses do indicate that the control group, which was the laboratory/discussion group, was advantaged over other groups. The analysis of variance indicated that the lessons which were controlled by the laboratory format were superior to the demonstration group for concrete students and the analysis of covariance indicated that this same laboratory group was superior to the reading format group for concrete students.

The results of this analysis indicate that the format of the learning cycle does not seem to make any significant differences insofar as short term learning is concerned. However, as far as long term retention of the information is concerned formal operational student seems to be advantaged by reading where as the concrete operational student seems to be advantaged in situations where there is a laboratory format.

Attitude Analysis

Attitudes were measured as previously with the BAR Attitude Inventory and by spontaneous written comments which were encouraged from all students concerning the lesson.

Table 6-14 summarizes the analysis of variance between the four experimental classes on the contentment factor of the BAR inventory. As can be seen from that table there was a significant difference between classes, which was identified using the Newman-Keuls, which had class 11, 22 and 25 significantly greater than class 16. Class 16 was the reading group and as can be seen from this, students were much less satisfied or pleased with this form of the learning cycle than with the laboratory/discussion, demonstration, or lecture form.

Table 6-15 summarizes analysis of variance for the BAR comprehension factor. From this analysis it can be seen that students attitudes towards how well they comprehended the material was not different between the various classes. In other words, students felt that no matter what form utilized, they learned about the same amount as students in other classes using different forms of the learning cycle.

Appendix 6D contains the tally sheets for the spontaneously written comments written on the back of the BAR sheets. There were significantly more negative spontaneous comments in the reading group, section 16 (11 statements) and in the teacher control group involving lecture, section 11 (10 statements) versus the demonstration group, section 25 (1 statement) and the control group, section 22 (no negative statements). The statement originated from the reading group and the lecture group, had two main themes. First of all, these students like doing laboratory and wish that they could in order to learn the material that was being taught. Secondly, they were bored by the reading and/or lecture material. The control group had very few statements overall. The lesson control demonstration group (section 25) had a few statements but even among these few there were some

TABLE 6-14: LC-7: SIMPLE CHEMICAL REACTIONS
ANOVA for BAR Contentment Factor

Source of Variation	DF	Mean Square	F	P
Class	3	197.7	6.65	0.0005 *
Error	87	29.7		

Least Square Means

Class	Contentment	
11	27.0	11 > 16
16	22.7	
22	28.8	22 > 16
25	28.9	25 > 16

TABLE 6-15: LC-7: SIMPLE CHEMICAL REACTIONS
ANOVA for BAR Comprehension Factor

Source of Variation	DF	Mean Square	F	P
Class	3	7.5	0.32	0.81
Error	83	23.4		

Least Square Means

Class	Comprehension
11	30.4
16	29.4
22	30.2
25	30.7

calling for laboratory work.

The summary of the attitude information seems to indicate that students are dissatisfied with lecture or reading type materials, although they do not particularly think that they are harmed by being presented with learning in this way. As a corollary to this, students seem very much to like laboratory material and there is some indication that the demonstration is not considered a substitute for the laboratory material by at least some of the students.

Conclusions

The question of this particular learning cycle experiment was whether the formats that controlled a lesson influenced the achievement attitudes of students involved with that lesson. Four different formats were used in the lessons in LC-7. The first of these, which was the control format, was the normal learning cycle format which was characterized as a laboratory/discussion. The second of these formats was reading. The third was a demonstration and the fourth was a lecture. The demonstration and lecture formats were thought of as being teacher controlled whereas the readings, of course, were controlled by the reading materials themselves. The discussion/laboratory was more student controlled. The overall question of this experiment was whether one of these formats had some advantages or disadvantages when compared with the others.

As far as attitude was concerned, there was some indication that reading was disadvantaged from the point of view that students contentment or their feelings of pleasure with the lesson were decreased over the other sections which had different formats. Many students, however, had confidence in what they learned. This was based on the comprehension factor of the BAR evaluation.

There is some indication that at least among the concrete students, this confidence might be misplaced. Insofar as short term is concerned, there doesn't seem to be any differences between the various different formats. Long term retention, however, shows that, for concrete students, laboratory/discussion formats are better than reading or teacher controlled demonstration formats.

For formal students reading seems to have some advantages over laboratory/discussion formats. One possible explanation for this result is that the readings, which give a concise summary of the information, might be better utilized by formal students than the laboratory/discussion format where they would have to develop their own summary. Because these formal students could retain this concise summary information better than concrete students, it might be more useful to them over a long term retention. This same effect would not be noticed by concrete students. It was also found that formal students scored better than concrete students in the demonstration and the reading formats. Once again reading, being an abstract way of presenting laboratory information. It is not surprising that formal students are better than concrete students of getting information from the reading format. This also seems to be true for the demonstration format. Formal operational students seem better at extracting this information than concrete students as far as long term retention is concerned.

The laboratory/discussion and the lecture formats seem to be about the same in helping both formal and concrete students in long term retention. It may be that the lecture format operates this way for different reasons. There were so many comments indicating students were basically unhappy or bored with the lecture format that both concrete and formal students may not have extracted the information from these lectures for that reason. There also doesn't seem to be any difference between formal and concrete students as far as laboratory/discussion format is concerned since this is basically a concrete presentation of information.

CHAPTER SEVEN

LC-8: REDOX REACTIONS

A NECESSITY EXPERIMENT

Experimental Design

LC-8 was designed to teach the concept of Redox (oxidation-reduction) Reactions. As invented during the activities of this learning cycle, the concept was stated as follows: some chemical reactions involve a change in the electron structure of atoms; oxidation is the process of losing electrons and reduction is the process of gaining electrons. This learning cycle expands on the idea of a chemical reaction originally developed in LC-7.

This learning cycle was designed as a necessity experiment and as such was the second necessity experiment performed (See also LC-5). There is also information concerning the necessity variable to be found in LC-2 and LC-12. Table 7-1 summarizes the experimental plan for manipulation of this variable. As in LC-5 five chemistry classes were involved. Four experimental groups tested the necessity of a phase by eliminating it. As in LC-5 two versions of the I phase were utilized. I_2 was a lecture. I_1 was a discussion. Unlike LC-5, form B of the CAT was administered after the invention phase of every class phase for sections 16 and 22, this test served as the post-test and was labeled CAT 3 for these groups. The practical outcome of this was that classes 11 and 14 had an intermediate test. It was hoped that this intermediate testing would help us interpret the role of various phases of the learning cycle. The B form of the CAT was also administered as a pre-test and as a post-test.

Description of Classroom Activities

Learning cycle 8 was used as a Necessity Experiment. Each learning cycle normally contains a gathering data phase (G), an invention phase (I) and an expansion phase (E). This experiment was designed to test the necessity of having each of these phases. There were five classes used, each of which had a different

TABLE 7-1

LC-8: Experimental Plan

Class	Pretest form B CAT 1	Phase 1	Phase 2	Post I form B CAT 2	Phase 3	Post test form B CAT 3
11*		G	I_1		E	
14		no G	I_2		E	
16		G	I_2		no E	
22		G	I_1		no E	
25		G	no I		E	

*Control

phase deleted from the learning cycle. Each phase of the learning cycle was conducted without modifications, if possible. For the classes which dropped the G phase, it was necessary to vary the approach used in the I phase. Since the invention discussion (See Appendix 7B) is directed by the data collected in G, the I was changed to a lecture which covered the same material. There were two class groups, GI_1 and GI_2, which differed by the approach used in the invention phase. For the class GI_1, the invention was a discussion of the data collected in G and for the GI_2 class, the invention was a lecture over the same information as the discussion covered. Student handout materials used during LC-8 have been reproduced in Appendix 7B.

The specification of classroom activities by sequence and class days is summarized in Table 7-2. Appropriate appendix page numbers are given in parentheses.

Post Experiment Discussion

As with previous experiments, the principle investigator and the two participating teachers held a post-experiment discussion concerning Learning Cycle 8. During this discussion, reactions to the observations of the classes, and thoughts concerning the activities of the Learning Cycle 8 were discussed. Learning Cycle 8 was a necessity experiment with class 11, the control group, containing all three phases of the learning cycle. The other classes eliminated one of the phases of the learning cycles.

The instructor of class 22, which eliminated the exploration phase and class 25, which eliminated the invention discussion, indicated that he felt that his students did not learn the material in the learning cycle very well. He said, "If you ask any student in any of my classes what oxidation is, they will tell you that it is an apparent loss of electrons. In fact, most of them, I wouldn't say all of them, but most of them would go ahead to say that that meant

TABLE 7-2

LC-8 - Classroom Activities

	11 G, I, E	14 I, E	16 GI#2	22 GI#1	25 GE
1	G Lab (7A-2 through 7A-5)	Invention Lecture (7B-6, 7B-7)	G Lab (7A-2 through 7A-5)	G Lab (7A-2 through 7A-5)	G Lab (7A-2 through 7A-5)
2	Idea Questions Small Group Discussion of Questions (7A-5)	E Demonstration (7A-6)	Invention Lecture (7B-6, 7B-7)	Idea Questions (7A-5)	E Demonstration (7A-6) (7B-8)
3	Invention Discussion (7B-2 through 7B-4)	Reading and Questions (7A-7 through 7A-9)	--------------	Invention Discussion (7B-2 through 7B-5)	Reading & Questions (7A-7 through 7A-9)
4	E Demonstration (7A-6)	--------------	--------------	Invention Discussion Continued	------------
5	Reading and Questions (7A-7 through 7A-9)	--------------	--------------	--------------	------------

that the element becomes more positive than it was before. They will give you a similar definitional answer for reduction and will tell you what a spectator ion is. But if you throw a half reaction at them they start getting tipsey." Both teachers indicated that they felt that the students were having more trouble with this unit than they did the previous year when the same unit was taught. In fact, both instructors indicated that they thought that the students were having as much trouble with this concept as they did with the mole concept, which traditionally is as difficult a concept as the students cover all year. Both instructors indicated support for this conclusion from an examination that they gave after this unit was over. They indicated that the examination scores were lower than normal on this unit. They did feel that the students seem to be able to write equations, half-reactions, and identify what materials was oxidized and what materials reduced. But they didn't seem to be able to deal with the idea of oxidation-reduction, and had a difficult time identifying species that lost and gained electrons. Both instructors indicated that they were going to spend some more time on the concepts even though the learning cycle itself was completed.

Each teacher had specific comments on the individual classes. The instructor who had the control group, section 11, indicated that this group had some real success with the idea questions in determining the products of the reactions using laboratory evidence. They still were having some trouble with the concept when they got to the reading questions. This instructor did feel that they could balance oxidation-reduction equations, that they could identify what was oxidized and what was reduced, and they could identify spectator ions.

In commenting on class 14, which was the class that had no G phase, the teacher indicated that after they had finished the invention discussion and went into the laboratory, it was as if they had never heard the invention discussion/

lecture at all. "There was not any transfer whatsoever from the lecture to the laboratory." One of the observers indicated that the same phenomenon is observed with the pre-lab discussions held for traditional laboratory activities. The feeling was that instructors very often waste their time with pre-laboratory discussion insofar as they are used as an introduction to the concept. Students at the high school and college level both act as if they didn't know anything at all about what was discussed in these pre-laboratory discussions. They act as if they had not had a pre-laboratory discussion at all. This observation supports the necessity of assimilation. If one hasn't got a structure system to assimilate the information in the pre-laboratory discussion, the students are not going to assimilate it. As a consequence, the information is not available for the laboratory itself.

The instructor who had class 16, which had no expansion phase, indicated that she felt her students were not through with the concept after the invention discussion. This instructor felt that after the invention discussion the students could give a definition of oxidation and a definition of reduction, but couldn't use the concept in any reasonable way. The instructor who had both class 22 and 25 indicated that he didn't see a lot of difference in learning between the two different classes immediately after the learning cycle itself. He felt that class 25, which did not have an invention discussion, didn't suffer in their ability to function immediately afterwards. His feeling was that the expansion phase served as to invent the concept.

The principle investigator indicated some concern that the CAT examination used for this learning cycle was much too difficult, and as a consequence would not be sensitive enough to measure what the students had learned. Neither of the classroom instructors felt this. Both of them indicated that their students had spent quite a lot of time doing the post-test which indicated to them that the student had much to say about the questions. One of the teachers said, "I noticed that all of my classes spent a long time writing the post-test, which I haven't looked at, but which tells me that they had something useful to write. Otherwise, they wouldn't have spent so much time on it."

Both classroom instructors indicated that they thought there was a relationship between how well the students did during this learning cycle and what they had done in earlier learning cycles, especially LC-6 and LC-7. One of the teachers said, "The class who had done the reading in Learning Cycle 7 could not even write a single-displacement reaction, which obviously gave them some problems when we started writing the equations for the idea question." The other instructor said, "Students were obviously applying the stuff that they had learned in Learning Cycle 6." There was some feeling that there might be a confounding effect of earlier learning cycles with this learning cycle. Because of the cumulative learning effect of many of the concepts of chemistry being related to earlier concepts, a confounding effect between this learning cycle and other ones might influence the various sections in a different way, depending upon the learning formats and the nature of the experiment from earlier learning cycles (especially those of Learning Cycle 6 and Learning Cycle 7).

Case Studies

One student was chosen as a case study for each of the five classes observed during this learning cycle. Although the students were chosen at random, they were not considered to be necessarily representative of their classes. It was felt, however, that they could serve to help interpret other observational and test data and give insight into various aspects of learning with the learning cycle approach.

Case Study 15. The teacher described this case study as a gregarious, intelligent student. If you were to observe him in the classroom setting, it was

TABLE 7-3

CASE STUDY PROFILE

Student	15		Variable	Necessity
Sex	M		Group	GIE Control
Class	11		LC 8	test scores (unadjusted)
Grade Level	11th			
Birthday	03-05-65		CAT 1	33 %
I.Q.	122		CAT 2	33 %
GEFT[1]	11	(Quartile 2)	CAT 3	56 %
VH[2]	5			
FR[3]	5			
CC[4]	5	5		
Grades[5]	B	A	A	A

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

difficult to find him seriously at work. However, he was more attentive and involved in classroom activities than the observer might think. He would ask questions during class discussion to clarify any points that he did not understand. His excellent memory of material we had covered and his willingness to participate in the class discussions made the case study an asset to his class. A profile of CS-15 is in Table 7-3.

Learning Cycle 8 was a Necessity Experiment. A regular learning cycle consists of three phases: (1) a gathering data (G) phase, (2) an invention (I) phase, and (3) an expansion (E) phase. A necessity experiment omits a phase of the learning cycle to see the effects on students' understanding of the concept of the learning cycle. The case study was in the control group, therefore, all three phases of the learning cycle were performed. Interviews were held before (pre-LC), during (post-G and post-I) and after (post-E) the learning cycle to determine the case study's understanding of the concept at the various points of the investigation. The central concept of learning cycle 8 was that some chemical reactions involve changes in the electron structure of the atoms. Each interview centered around two questions: (1) What is a chemical change and explain what happens during a chemical change? and, (2) Given the equation $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$, state whether it is a chemical change and discuss the reasons for your choice. Excerpts from the case study interview tapes will be used to illustrate the points made about the student's understanding or misconceptions. I will designate comments or questions by the interviewer and CS will stand for the responses by the case study.

During the pre-LC interview the case study indicated he had an excellent foundation in the course. He constantly referred to previous lessons to support his statements. There is some confusion and his terminology is weak concerning ions. When he mentions losing and gaining of electrons, he is referring to ion formation. His theoretical explanation for a chemical change is that the ions are regrouping such as in a double displacement reaction.

I: What happens when a chemical change takes place?

CS: Atoms change themselves to form with other ions and it changes the substance--the reactants to form the products.

I: Can you give me some examples of what you mean?

CS: Magnesium burned in air to form magnesium oxide. The particles inside of magnesium were changed.

I: What do you mean by it changes particles?

CS: It adds ions of oxygen to the magnesium, so it changes color and texture.

I: So, it changes some physical properties, but what is happening to the chemicals?

CS: They are regrouping--losing and gaining electrons.

I: What do you mean by regrouping?

CS: They regroup with other electrons or other parts in the reaction medium.

I: Can you give me an example of this?

CS: $KI + Pb(NO_3)_2$ are both white or basic colors and one turned yellow. They were in water. I can't really remember the lab.

I: OK, you had a water solution of KI and a water solution of $Pb(NO_3)_2$ and you mixed them together.

CS: They formed a precipitate that was filtered out and a substance that was dissolved in the bottom of the beaker. Those two reacted together to form totally different substances.

I: What were those substances?

CS: Lead iodide and potassium nitrate.

I: Is this an example of gaining or losing electrons?

CS: I guess not because they have the same number of electrons as to begin with.

I: Is it a chemical change?

CS: Yes, because it cannot be reversed by physical means. There was a precipitate formed.

I: When I look at the equation--$Pb(NO_3)_2 + 2KI \rightarrow 2KNO_3 + PbI_2$--how do I know a chemical reaction is taking place?

CS: Because it is a double displacement reaction.

I: How does that tell me there is a chemical reaction?

CS: That's the way chemicals react to form different characteristics.

I: Let me ask the question a different way. Can you give me an example of a physical change?

CS: Melting ice.

I: Oh, let me write the equation for that--$H_2O_{(s)} \rightarrow H_2O_{(l)}$--how do I know when I look at this equation that it is not a chemical reaction?

CS: Because there's not a change to that substance--no chemical change--the same atoms are in it.

I: In the equation $Pb(NO_3)_2 + 2KI$ the products have the same atoms in them?

CS: But they are with different atoms.

I: You are making a distinction between these two equations by whether the atoms are grouped in different combinations after the reaction than they were before the reaction.

You were talking about losing and gaining of electrons. Where did that idea come from?

CS: They have to gain or lose electrons so they form together by ionic bonding.

During the post-G interview the case study demonstrated that he had assimilated the laboratory activities. This was shown by his excellent memory of the laboratory procedures and his vivid description of the reactions. There were two reactions in this laboratory activity which gave similar results. The case study demonstrated he was in a state of disequilibrium when he treated the two reactions differently. However, he is sure enough of his information to propose explanations. Although the case study did not see the electron transfer, he seems to know that his explanation of regrouping of atoms is not enough to explain all chemical reactions.

I: Would you describe what you did in the laboratory?

CS: We put a piece of mossy zinc in a clear blue $CuSO_4$ solution. Observed the effects of $CuSO_4$ on the zinc. They we put in 15 drops of H_2SO_4 and observed.

I: What did you observe?

CS: When we first put the zinc in the $CuSO_4$ solution, it turned rust color and mossy texture. There were some bubbles forming. They we added the acid, it bubbled more, heated the test tube, and it turned more brown.

I: What do you think the brownish material is?

CS: I imagine it is zinc oxide because when metal oxides it turns like rust.

I: Did anything happen to the solution?

CS: It turned colorless.

I: What do you think the bubbles were?

CS: Gas.

I: What do you think the gas was?

CS: .....

I: What possibilities are there?

CS: Hydrogen, oxygen, sulfur gas.

I: What about the second part of the experiment?

CS: We put a piece of mossy zinc in $CuCl_2$ solution. It turned the metal the same rusty color and mossy appearance.

I: What does that tell you?

CS: Copper is interacting with the zinc because you didn't have any oxygen like in the first reaction. You had copper in both reactions. One reaction had sulfate in it and the other reaction had chloride. The effects of both reactions are the same.

I: What do you think accounts for the blue color of the solution?

CS: It was apparent in both solutions so it must be copper.

I: What is copper?

CS: It's a metal.

I: What does it look like?

CS: Brownish, bronze looking...I don't know why it would turn it blue unless that is the way it usually reacts in a solution.

I: What happens when a chemical change takes place?

CS: Reorganizes the atomic structure of the substance. The atoms form with different atoms to form a new substance by ionic bonding. This can happen by double displacement. Synthesis is when two reactants form together to form one; like, hydrogen and oxygen form together to produce water. Decomposition is when one reactant is split apart to form two products.

I: Does that involve the rearrangement of atoms?

CS: The atoms are not rearranged. They are in different combinations.

I: In all of those cases you are describing a change in the combinations of the atoms, did I show you this one before? Is this $Cl_2 + 2Br^- \rightarrow Cl^- + Br_2$ a chemical reaction?

CS: Yes, they have different properties after the reactions. The atoms are different.

I: In that particular case I haven't put a new combination of atoms together.

CS: Bromine got the chlorine properties and chlorine got the bromine properties.

I: What kind of properties are you talking about?

CS: Ionic properties—bromide is negative one and after the reaction is Br_2.

I: How does that happen?

CS: I don't have any idea.

During the post-I interview it was obvious the case study had developed some of the language to deal with the reactions. Some of his previous ideas were still present: (1) The copper was responsible for the blue color, and (2) Some reactions involve the rearrangement of atoms. He had accommodated, at least partially, the idea of loss and gain of electrons as criteria for determining a chemical reaction. During this discussion a misconception became apparent concerning the use of a subscript to determine the change of an ion.

I: What kind of things did you learn from this lab?

CS: I learned how to look at a test tube, watch the reaction take place and use that to make a formula for the reaction.

I: Compare the two systems you studied in the laboratory.

CS: Both systems involved oxidation-reduction and spectator ions. I learned that today. They both involved single displacement reactions. Usually when you have a single displacement reaction, it will involve oxidation-reduction and a spectator ion. Both experiments produced a gas and a clear, colorless solution. Both systems ended up with copper in the bottom of the test tube and both produced heat.

I: How are the systems different?

CS: One did not produce as much gas.

I: Was it the same gas produced?

CS: Both experiments produced hydrogen.

I: How did you know that?

CS: We tested it.

I: What accounts for the blue color in the original solution?

CS: I guess the copper because it was evident in both $CuSO_4$ and $CuCl_2$ so the sulfate and chloride must not be part of it.

I: I thought copper was a metal. Wasn't it one of the products?

CS: Yes.

I: Did you have copper at the beginning?

CS: Yes, we had the solution.

I: Is that copper?

CS: Another evidence we had was that both solutions ($ZnSO_4$ and $ZnCl_2$) after the reaction were clear and colorless.

I: When I look at the equation for a chemical reaction how do I know that a chemical reaction has taken place?

CS: Different formation of the ions. You start with $CuCl_2$ and Zn and end up with $ZnCl_2$ and Cu. The Zn displaced the Cu.

I: Is $H_2O_{(s)} \rightarrow H_2O_{(l)}$ a chemical change?

CS: No, it would be a physical change.

I: Why do you recognize that as a physical change?

CS: There's no change in the chemical (H_2O) itself.

I: Is $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$ a chemical change or physical change?

CS: Is Br_2 neutral?

I: It doesn't have a charge on it, so it must be.

CS: I would say it is a chemical change because it gained an electron.

I: What gained an electron?

CS: Chlorine, it had a reduction.

I: Does that mean that chemical changes have to involve a change in electrons?

CS: For a guess I would say yes.

I: Have you had any examples of a double displacement reaction?

CS: Yes, the lead nitrate and potassium iodide reaction.

I: This is the equation for that reaction: $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$. Is that a chemical reaction?

CS: Yes.

I: How do you know that is a chemical reaction?

CS: The positive ions form with different negative ions, so that's a chemical change.

I: Is there an oxidation reduction going on there?

CS: Yes, I think, with the nitrate and the iodide. There's two nitrate on the left so it had a negative two charge and on the right it has a negative one charge. There was an oxidation when it lost an electron.

I: Oh, explain that to me.

CS: If you have 2 nitrate ions, each nitrate ion had a negative one charge, so that has a negative 2 charge which means it has 2 extra electrons. On the product side it has a negative one charge which means it has lost an electron.

I: What happened to the electron?

CS: It went to the iodide. On the left it has +1 charge and in the products it has a -2 charge.

During the post-E interview the case study demonstrated that he had accommodated the idea of electron transfer in chemical reactions. The accommodation process had started in the invention phase but was completed during the expansion activities. He was able to describe the chemical cell demonstration and to write equations for the students. The case study was able to use theoretical explanations to analyze the reactions.

I: I'm going to give you three equations. I would like you to tell me what kind of equation each is and what it signifies.

Equation 1: $H_2O_{(s)} \rightarrow H_2O_{(l)}$

2. $Br_2 + 2Cl^- \rightarrow Cl_2 + 2Br^-$

3. $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$

CS: Equation 1 shows a solid going to a liquid so it means it gained kinetic energy. It is a physical reaction because there is no electron change or other changes from reactants to products.

I: What about equation two?

CS: There is a change in the charges.

I: What do you mean by that?

CS: Chloride comes over here to form chlorine gas which is neutral. They you have bromine which is neutral and in the products it gained an electron from chloride to form bromide.

I: So, what's happening to the electron?

CS: Chloride is losing an electron. Bromine is picking up the electron to become bromide.

I: Is that a chemical or physical change?

CS: Chemical.

I: What about the third equation?

CS: It is a double displacement reaction and chemical change.

I: How do you know that is a chemical change?

CS: The products are different than the reactants. $Pb(NO_3)_2$ forms with I^- to make PbI_2. K which loses I^- and forms with NO_3^- to make KNO_3, so you have two new products.

I: Are electrons gained or lost in that process?

CS: No, it doesn't look like it. There are not any electrons gained or lost.

In summary the case study made a clear progression through assimilation and accommodation. At the end of the learning cycle he was using a theoretical model to analyze chemical reactions. He would look for atom rearrangement and electron transfer to identify if there were any new substances formed.

Case Study 25. The teacher described the case study as an average student. She was active and involved in the classroom activities but satisified to have questions left unanswered. Her peers thought of her as a capable student who they would ask for help. At various times during the school year the case study was ill and missed several days of class. Even though she was very conscientious

TABLE 7-4

CASE STUDY PROFILE

Student	25		Variable	Necessity
Sex	F		Group	IE
Class	1[illegible]		LC 8	test scores (unadjusted)
Grade Level	11th			
Birthday	11-08-64		CAT 1	33 %
I.Q.	107		CAT 2	44 %
GEFT[1]	18	(Quartile 4)	CAT 3	33 %
VH[2]	3			
FR[3]	5	4		
CC[4]	5	5		
Grades[5]	B	B	B	B

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

about making up the assignments, there seemed to be gaps in her understanding of the material. A profile of CS-25 is in Table 7-4.

Learning cycle 8 was used as a Necessity Experiment. A learning cycle normally consists of three phases: the gathering data (G) phase, the invention (I) phase, and the expansion (E) phase. The necessity experiment was investigating what happens to a student's understanding of the concept of the learning cycle with one phase of the learning cycle being deleted. The case study was in the test group, IE. The invention phase normally consists of a class discussion of the data collected during the G phase. Since G was omitted, it was necessary for I to become a teacher lecture covering the same topics as regular discussion would. The E phase was conducted the same as E in the control group. This consisted of a teacher demonstration of a chemical cell and a reading. Interviews were held with the case study to determine her understanding of the concept at various stages of the investigation. Three interviews were held: (1) a pre-learning cycle interview to establish what the case study knew about the concept of LC-8 prior to the investigation, (2) a post-invention interview--this interview would show any effects the invention lecture had on the case study's thoughts about the concept, and (3) a post-expansion interview--this interview was to determine if the E phase or the investigation as a whole had caused any changes in the case study's understanding of the concept. These interviews will be referred to as pre-LC, post-I, and post-E, respectively. The central concept of learning cycle 8 was that some chemical reactions involve changes in the electron structure of the atoms. There were three basic questions asked in each interview: (1) What is a chemical change? (2) What happens during a chemical change?, and (3) Given the equation $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$, state whether it is a physical or chemical change and discuss the reasons for your choice.

During the pre-LC interview the case study defined chemical changes in terms of observational evidence. She explained that substances combine by losing and gaining electrons; however, the case study was actually referring to ion formation. When asked to discuss a chemical change involving the transfer of electrons, she had difficulty explaining the change in charge.

Excerpts from the case study interview tapes will be used to illustrate the summary points. I will designate questions by the interviewer and CS will designate responses given by the case study.

I: What is a chemical change?

CS: When two chemicals are put together they change color or form a precipitate?

I: What actually happens to the substance when a chemical change occurs?

CS: They combine together.

I: Can you be more specific? Since all matter is made up of atoms, it must be something involving the atoms.

CS: Two chemicals--negative and positive--lose or gain electrons and bond together.

I: What causes them to bond together?

CS: Ionic bonding.

I: What's ionic bonding?

CS: Positive atoms gain electrons and negative atoms lose electrons.

I: Is $H_2O_{(g)} \rightarrow H_2O_{(e)}$ a chemical change?

CS: No, it is still the same chemical.

I: Is $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$ a chemical change?

CS: I would say it's the same thing.

I: Do you mean the same thing on the left as on the right?

CS: The Br has changed charge so it would be a chemical change.

I: Would you explain to me why that is a chemical change?

CS: The chlorine and bromine have changed charge.

I: How does that happen?

CS: The Br got a positive charge.

The case study in the post-I interview defined a chemical change as a loss or gain of electrons. She had not accommodated this information from the I lecture because she could not apply it to the equation $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$. Also she was still describing ionic bonding when asked to give an example of a chemical change.

I: Last time we discussed the equation $Cl_2 + 2Br^- \rightarrow 2Cl^-$. Is that a chemical change?

CS: I think it is physical. If it was chemical they would have changed form and they look almost exactly alike.

I: When you have Cl_2 what are the Cl atoms like?

CS: They are negatively charged so the ones on the left are like the ones on the right.

I: What is the charge of the Cl in the reactants?

CS: Negative 2.

I: $2Br^-$ are negative. Is Br_2 negative?

CS: Wait a minute. Isn't Br_2 a diatomic molecule?

I: Yes.

CS: Then the 2 means...I don't know.

I: What happens to the atoms in a chemical change?

CS: They lose or gain electrons.

I: Can you give me an example of that?

CS: Sodium...something with sodium. Na is a +1 so it would react with something with a -1 charge to form a chemical change.

I: Why would that be a chemical change?

CS: Na would lose one electron to go the negative charged one and the negative one would gain an electron.

I: Would they be positive and negative before or after this exchange of electrons?

CS: They would be positive and negative before the transfer and neutral afterwards.

During the post-E interview the case study reverted to her pre-LC definition of a chemical change using observational evidence. Although there is still confusion in her thoughts about the concept of LC-8 there was some accommodation during this interview concerning the transfer of electrons involved in a chemical change.

I: Is $NaCl \xrightarrow{H_2O} NaCl_{(aq)}$ a chemical change?

CS: No.

I: Why isn't it?

CS: You can evaporate the water out and still have NaCl. It hasn't changed any of its properties.

I: What is involved in a chemical change?

CS: Two chemicals that react together to change color or texture or form a precipitate.

I: Is $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$ a chemical change?

CS: From what we learned yesterday, the Cl_2 is neutral and the Br with a negative charge is a -2 since there's 2 of them. The Cl^- is also -2 and the Br_2 is neutral. So, I would say it is not a chemical change.

I: Would you explain to me why it is not a chemical change?

CS: ...I just changed my mind. If Cl_2 gains 2 electrons which made it a -2 and the Br lost 2 electrons which made it neutral, so it was a chemical change.

I: Let's look at another equation. You did this lab earlier in the year. Is $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$ a chemical change?

CS: No, because the ions trade places but keep the same charges. Isn't this a double displacement?

I: Yes, is a double displacement a chemical change?

CS: I don't know.

I: Are you saying that is not a chemical change because the charge on the ions remains the same?

CS: Yes, nothing loses or gains electrons but is a double displacement is a chemical change then it would be.

I: What evidences did you give me that indicates a chemical change?

CS: Change in color, change in texture...it would be a chemical change because it changed from two liquids to a precipitate.

I: If both of these equations are chemical changes, what's the differences between them?

CS: The $Pb(NO_3)_2 + 2KI \rightarrow 2KNO_3 + PbI_2$ forms a precipitate and $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$ doesn't?

I: Are there any other differences?

CS: The $Pb(NO_3)_2 + 2KI \rightarrow 2KNO_3 + PbI_2$ is a double displacement reaction and $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$ is an oxidation-reduction reaction.

I: Are you saying the $Pb(NO_3)_2 + KI$ is not an oxidation-reduction reaction?

CS: I would say it is not an oxidation-reduction reaction.

The case study had a very tenuous understanding of the concept of Learning Cycle 8. By using logic she usually came up with the right answers to the questions. Although when asked to compare the models she had built, the observational data would surface again. The case study was in a state of disequilibration.

Case Study 511. The teacher described this case study as a very quiet, interesting student. She was transferred into class 16 at the semester break. Because of her rather timid nature it was a few weeks before she was very confident of herself in this class and with a different teacher. After her initial adjustment

TABLE 7-5

CASE STUDY PROFILE

Student	511			
Sex	F			
Class	16			
Grade Level	11th			
Birthday	01-12-65			
I.Q.	-			
GEFT[1]	-	(Quartile -)		
VH[2]	-			
FR[3]	-	4		
CC[4]	-	-		
Grades[5]	-	-	A	A

Variable Necessity

Group GI$_2$

LC 8 test scores (unadjusted)

CAT 1 44 %

CAT 2 - %

CAT 3 44 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

period she became an excellent student. The case study was very involved in her studies and would ask probing questions if she felt a lack of understanding. A profile of CS-511 is found in Table 7-5.

Learning Cycle 8 was used as a Necessity Experiment. A learning cycle normally consists of three phases: the gathering data (G) phase, the invention (I) phase, and the expansion (E) phase. The question the necessity experiment is addressing is what happens to a student's understanding of the concept of the learning cycle with one phase of the learning cycle being deleted. The case study was in the test group, GI_2. The G phase consisted of a laboratory activity as did the G phase in the control test group. However, the I phase was changed from a discussion to a teacher lecture which covered the same material. Interviews were held with the case study to determine her understanding of the concept of Learning Cycle 8. Three interviews were scheduled: (1) a pre-learning cycle interview--to find out what information about the concept of LC-8 the case study had prior to the investigation, (2) a post-gathering data interview--this interview would show any effects the G phase had on the case study's understanding of the concept, and (3) a post-invention interview--this interview was to determine if any change in understanding had occurred as a result of the invention phase or both the G and I phases. These interviews will be referred to as pre-LC, post-G, and post-I, respectively. The central concept of learning cycle 8 was that some chemical reactions involve changes in the electron structure of the atoms. There were three basic questions asked in each interview: (1) What is a chemical change? (2) What happens during a chemical change?, and (3) Given the equation $Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$, state whether it is a physical or chemical change and discuss the reasons for your choice.

During the pre-LC interview the case study was able to state the difference between physical and chemical change. However, when asked to explain what happens during a chemical reaction, she didn't know. The following are excerpts from the case study interview tape which will illustrate the above comments. I will be used to designate the questions asked by the interviewer and CS will designate the responses given by the case study.

I: What is a chemical change?

CS: A physical change changes the phase or state by spreading the atoms apart or moves them closer together to make it solid, liquid, or a gas. A chemical change actually changes the substance by rearranging the atoms into different compounds.

I: Is $H_2O_{(g)} \rightarrow H_2O_{(e)}$ a chemical change?

CS: No.

I: Why do you think that is not a chemical change?

CS: In a gas and a liquid there are the same atoms. The atoms are just father apart in a gas than in a liquid.

I: What happens when a chemical change occurs?

CS: Atoms are being changed..I don't think I really know that.

I: Is this a chemical change--$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$?

CS: I don't think it would be a chemical change.

The G phase of the learning cycle did not change the case study's definitions for chemical and physical change. She seemed to have some awareness of chemical reactions but certainly did not have a theoretical basis for explaining how they occur. The following excerpts are from the post-G interview tape.

I: Give me an example of a physical change.

CS: If you have a liquid and spread the molecules apart, it will change to a gas.

I: OK, give me an example of a chemical change.

CS: In a chemical change the substances are actually changed to something else. Some of the evidences of a chemical change are heat production, gas production or a color change.

I: If I put salt, NaCl, in water and it dissolved, would that be a chemical change? I would write it like this: $NaCl + H_2O \rightarrow NaCl_{(aq)}$.

CS: No, when you put NaCl in water it ionizes.

I: What does that mean?

CS: Water break it up into its separate ions.

I: Is this a chemical change--$Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$?

CS: I don't think so. The Cl_2 as a reactant has been ionized. It's an ion in the products. The Br^- is an ion in the reactants and isn't an ion in the products.

I: Does this constitute a chemical change?

CS: No.

I: Is $2Na + Cl_2 \rightarrow 2NaCl$ a chemical change?

CS: I don't know. I guess it would be because on the left you have a metal and a gas and as a product you have salt.

I: Can you tell me what happens to the sodium in that reaction?

CS: I don't know.

The next phase of the learning cycle was an invention lecture. During the post-I interview the case study had attained the language of the concept; however, she was not able to apply it correctly to the equation that was given in each interview. She did show evidence of accommodation when asked to apply the concept to an equation for a chemical reaction that had been conducted in class.

I: What have you done in class since our last talk?

CS: Yesterday we learned about oxidation and reduction.

I: Is $NaCl + H_2O \quad H_2O_{(aq)}$ a chemical change?

CS: No.

I: Is $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$ a chemical change?

CS: Physical.

I: Would you explain to me why that is physical?

CS: You have the same products as you have reactants.

I: Let's look at $2Mg + O_2 \rightarrow 2MgO$. Is that a chemical change?

CS: Chemical.

I: Why would you say that is a chemical change?

CS: They combined.

I: Are you saying you have a different substance on the right than you have on the left because they have combined?

CS: Yes.

I: What happened to the magnesium from the left hand side to the right hand side?

CS: It would have had to lose electrons to combine with the oxygen. The oxygen had to gain electrons.

I: How does this relate to what you have been doing?

CS: Losing electrons was oxidation and gaining electrons was reduction.

I: Was this an oxidation-reduction reaction?

CS: Yes.

In summary the case study did not accommodate that the transfer of electrons constitutes a chemical reaction. In her post-G interview the case study identifies that in the equation $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$ the substances are changing from the neutral state to ions and vice versa. Even though the invention phase gave her the language for oxidation-reduction, she did not accommodate the idea to the above question.

Case Study 109. This student was described by his teacher as being very interested in theoretical speculation about the concepts being studied. This student's contribution to class discussions was significant and the entire class benefited from his part in the discussion. This student, however, did not do written work consistently and he often seemed distracted during times when basic, foundational material was being discussed It should be noted that this student, unlike any of the other in his section, had taken physics as a junior and was taking chemistry as a senior. This is the opposite of the normal procedure in this high school. A profile of CS-109 is found in Table 7-6.

The experiment in Learning Cycle 8 was a necessity experiment. The section of which this case study was a member was testing the necessity of the expansion (E) phase. The class performed the gathering data (G) phase and engaged in an invention (I) phase class discussion. The E phase was omitted. There were three interviews conducted with this case study: the first one was done just prior to beginning the learning cycle (pre-LC); the second one was done immediately following the gathering data phase (post-G); and the final interview was held after the class discussion in the invention phase (post-I).

Questioning of the case study followed two basic lines. The case study was asked to define a chemical change and to explain what was occurring during the process of a chemical change. Secondly, the case study was asked to inspect the equation $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$ and decide whether it was a chemical change or a physical change. The case study was asked to explain the reasoning that led to the conclusion drawn about the equation.

During the pre-LC interview the case study was able to give a good observationally-based definition of chemical change. When prodded by questioning, he discussed chemical change in terms developed during previous class discussions. The case study expressed uncertainty about whether the chlorine-bromide ion equation was a chemical change, but he was willing to hypothesize that it was a chemical change.

TABLE 7-6

CASE STUDY PROFILE

Student	109			
Sex	M			
Class	22			
Grade Level	12th			
Birthday	02-24-64			
I.Q.	120			
GEFT[1]	-	(Quartile -)		
VH[2]	-			
FR[3]	5	6		
CC[4]	-	6		
Grades[5]	A	B	D	B

Variable Necessity

Group GI_1

LC 8 test scores (unadjusted)

CAT 1 33 %

CAT 2 -- %

CAT 3 33 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.
2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.
4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).
5. Grades were given by the classroom teacher four times during the year.

I: What is meant by the term "chemical change"?

CS: It means the compound has changed its properties from being conductable or not, soluble in water or not, acid or base, color usually changes, and sometimes a precipitate forms.

I: When I look at a chemical equation, how can I tell that a chemical reaction has taken place?

CS: The rearrangement of the elements usually tells you. It goes from one compound to the next; usually an exchange of ions.

I: Would you say that this is a chemical change? (Interviewer wrote $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$ on a paper.)

CS: It could be. It's hard to tell without seeing the reactants themselves after being combined. But seeing that the chlorine has changed into just two ions, instead of being one molecule, I guess that could be deemed as a chemical change.

I: That isn't really technically a rearrangement of the atoms is it? Or is it?

CS: Well, the bond of the chlorine has been broken, so it's left with two 1- ions, and the bromine has been combined.

I: Can you say what has happened there?

CS: A switch in charge; a molecule of bromine formed; I don't know.

The case study had assimilated the laboratory experience very well by the post-G interview. He had done some tests that were not required by the written laboratory procedure (See Appendix 7A), and he was willing to speculate on the possible products of the reactions. His prediction of products indicated that he had a reasonably good understanding of ion charges. Interestingly, the case study changed his mind about the chlorine-bromide reaction. He now stated that the reaction was physical and not chemical, as he had stated in the pre-LC interview.

I: What do you think was happening in the first part of the first reaction? (The interviewer had been carrying on a dialogue with the case study about the laboratory reaction. In this question the interviewer is referring to the combination of zinc metal with copper (II) sulfate solution.)

CS: I think copper combined with zinc which caused the color of the substance in the bottom (of the test tube) to change.

I: Is this a chemical reaction?

CS: Yes...there is gas being produced, a color change, heat being produced, a physical change in the zinc.

I: Can you write an equation for this?

CS: Yes, I think so...(the case study wrote: $CuSO_4 + Zn + H_2SO_4 \rightarrow H_2$); copper is plus two here. This could be tough because zinc is also plus two. (At this point the interviewer suggested that the case study limit himself to the reactants zinc and copper (II) sulfate.)

CS: (wrote: $CuSO_4 + Zn \rightarrow ZnSO_4 + Cu$) But then that would be the sulfate combining with zinc, since the copper is a plus and Cu is left in solution.

I: What was copper in this reaction?

CS: The reddish color, since copper has a reddish color to it.

I: How do you account for some of the other things you saw?

CS: The black is SO_4 and zinc...$ZnSO_4$.

I: How can you tell, by looking at a chemical equation, that a reaction has occurred? For example, if I write $H_2O_{(g)} \rightarrow H_2O_{(1)}$, is that a chemical reaction?

CS: No. No new substances are formed; just a change in form.

I: Are new substances formed in a chemical change, then?

CS: Yes.

I: What is the source of these new substances?

CS: They come from compounds you mix together; molecules of different compounds break apart and re-form.

I: Is $2Br^- + Cl_2 \rightarrow 2Cl^- + Br_2$ a chemical reaction?

CS: No. I thought about this quite a bit and all that's happening is that an ion has changed into a molecule. $2Br^-$ have change to Br_2, and Cl_2 is changed to $2Cl^-$.

I: What's happening during this change?

CS: An electron from Br is being traded to Cl causing an ion.

During the post-I interview the case study treated systems as involving chemical changes or physical changes on the basis of clear differences in combination of elements. He maintained his misconception that the chlorine-bromide reaction was a physical change and the context of the interview indicates that the reason for his maintaining that viewpoint was the absence of a positive ion combined with the negative ions in the equation.

I: I'm going to write some equations down here and I'll ask you what is happening in each case. $H_2O_{(s)} \rightarrow H_2O_{(l)}$; $2Br^- + Cl_2 \rightarrow 2Cl^- + Br_2$; and $Pb(NO_3)_2 + 2KI \rightarrow 2NO_3 + PbI_2$.

CS: The first one is a physical change.

I: How to you know that it's physical rather than chemical?

CS: There's no displacement or decomposition of the compound.

I: What about the second one? Is there any displacement or decomposition of the compound?

CS: Just rearrangement of the electrons; not necessarily a chemical change.

I: Is it a physical change or a chemical change or what?

CS: Probably a physical change, not a chemical change.

I: What's happening there?

CS: It's an oxidation-reduction reaction, where the chlorine is getting electrons from the bromide ion. That's all.

I: What's going on in the third one?

CS: That's a single displacement, chemical reaction, where the potassium is exchanging places with the lead forming potassium nitrate and lead iodide.

I: Is that an oxidation-reduction reaction?

CS: No.

I: Are oxidation-reduction reactions chemical reactions or physical reactions?

CS: Either.

I: What happens when a chemical occurs?

CS: There is a change in properties of the compounds, a change of heat, gas can be produced, a precipitate, or a new substances formed somehow through the rearrangement of elements.

I: What do you mean by a new substance?

CS: Like the reaction of lead nitrate with potassium iodide forming lead iodide and potassium nitrate. There's something different in the system; a different compound.

I: When we look at a chemical equation, how do we know that a chemical reaction has taken place?

CS: Look for a change; a product that was not a reactant to begin with. If you start out with two reactants, then you may end up with two or three products, and so you would have a chemical change.

I: Is that the only possibility? Does that define all chemical reactions?

CS: Yes.

I: What about this oxidation-reduction thing; this loss and gain of electrons? Do all chemical reactions have to lose or gain electrons?

CS: No, just like in that last equation. Neither one lost or gained, they just traded places.

This learning cycle, as presented in this necessity experiment, did little to alter the case study's conception of chemical change. The final interview suggested that his conclusive evidence for determing whether a change is chemical or physical relied on the production of different combinations of ions or elements. The case study even developed a misconception regarding the nature of oxidation-reduction reactions, and this misconception still existed at the end of the learning cycle.

Case Study 132. This student was described by her teacher as being an overachiever. She was gregarious, highly involved in all classroom activities, and diligent in her preparation of assigned work. She was friendly to her classmates, and this trait enhanced her efforts to gain constructive assistance from them. A profile of CS-132 is found in Table 7-7.

The experiment of Learning Cycle 8 was testing necessity of the learning cycle phases. The section, of which this case study was a member, was used to test the necessity of the invention (I) phase by omitting it. The gathering date (G) phase and the expansion (E) phase were performed as written, with the exception that the terms "oxidation" and "reduction" were not used. Changes in charges were referred to only in terms of losing or gaining electrons.

Three interviews were conducted with this case study: the first one was held just prior to the beginning of the learning cycle (pre-LC); the second one was done after the gathering data phase (post-G); and the third interview was held following the expansion phase (post-E).

Questioning of the case study followed two basic lines. The case study was asked to define a chemical change and to explain what was occurring during the process of a chemical change. The interviewer either supplied example

TABLE 7-7

CASE STUDY PROFILE

Student	132				Variable	Necessity
Sex	F				Group	GE
Class	25				LC 8	test scores (unadjusted)
Grade Level	11th					
Birthday	04-12-65				CAT 1	33 %
I.Q.	108				CAT 2	-- %
GEFT[1]	4	(Quartile 1)			CAT 3	56 %
VH[2]	4					
FR[3]	3	3				
CC[4]	4	5				
Grades[5]	A	A	A	A		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

reactions in the questioning or used reactions that came from classroom interactions as the basis for questioning. Secondly, the case study was asked to inspect the equation $Cl_2 + 2Br^-$ $2Cl^- + Br_2$ and decide whether it was a chemical change or a physical change. The case study was asked to explain the reasoning that led to the conclusion drawn about the equation.

Although the case study stated observational evidence for chemical changes, she seemed to have almost no theoretical basis for identifying chemical reactions during the pre-LC interview. Careful leading by the interviewer indicated that the case study had assimilated some terminology, but she had not accommodated too much ot it. The major portion of the interview is included to illustrate these observations.

I: What happends when a chemical change takes place?

CS: It changes chemically. The evidence you can tell is by color change and a precipitate forms and a texture change but I'm not real sure what happens.

I: What happens to the atoms?

CS: During a chemical change, I guess that they react chemically with each other and they are either displaced and they lost atoms or gain atoms.

I: If you have written down a chemical equation, how do you know if it's a chemical reaction?

CS: I'm not real sure but I guess if it shows that it was balanced out; I don't know.

I: Let me show you a couple examples, and you tell me if they are chemical reactions. (wrote $H_2O_{(l)} \rightarrow H_2O_{(v)}$). Is that a chemical reaction?

CS: Yes.

I: What happened that made it a chemical reaction?

CS: I think because it went from a liquid to a vapor and there's a change in the chemical reaction. With a chemical change, you can't take it back to what it was before.

I: You can't take water vapor back to a liquid?

CS: Oh, no, I guess it wasn't then, because you can take it back...so it's a physical change because you can reverse it.

I: Looking at $NaCl_{(s)} + H_2O \rightarrow NaCl_{(aq)}$, is that a chemical reaction?

CS: I would think it wouldn't be because you could heat water and be left with NaCl.

I: How are these different from an equation where we have a chemical change? For instance, we worked with calcium and water and ended up with calcium oxide. Is that a chemical reaction? (Interviewer wrote: $Ca + H_2O \rightarrow CaO + H_2$).

CS: I'm not sure how to tell. Do you mean if it was a chemical change or physical change or a chemical reaction?

I: A chemical change would be a chemical reaction. What happened in this that made it a chemical reaction?

CS: The calcium has gone with the oxygen and then the hydrogen is left by itself...it was a single displacement, I think. It displaced the hydrogen and then the calcium went with the oxygen.

I: Now let's look at this reaction. (wrote: $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$). Just looking at that equation, would you say it was a chemical change or a physical change?

CS: I'd go with chemical change because you have Cl_2 over here and two atoms of Cl over here.

I: How are those two different?

CS: I don't know how to explain it.

During the post-G interview the case study was able to recall the observations made in the laboratory but she was unable to show any significant theoretical structure to support her observations. Her lack of structure for chemical changes, from earlier learning cycles, caused her great difficulty as she attempted to interpret the results of the current learning cycle.

I: Let's talk about a system you work with in lab. You combined zinc with copper (II) sulfate. Was that a chemical change?

CS: Yes, because of a color change, a little heat produced and a gas given off.

I: What happened to the atoms in that chemical change?

CS: Well, I guess they reacted chemically with each other and in the system, when they were added, I guess they broke apart and hooked on with new atoms.

I: I'll write the reactants. What are the choices for the products? (The interviewer wrote: $Zn + CuSO_4$).

CS: I guess zinc could react with copper...I'd have to look on my ion sheet.

I: Let me write an equation that we looked at before. (wrote $Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$) I asked you before if this is a chemical reaction and you said it was. You didn't know why so let me ask you again if you know why this would be an equation for a chemical reaction?

CS: The reason I think it is, is because the negative, that is the 2Br, and after the positives formed it switched over to the Cl.

(NOTE: The case study got rather confused at this point and after a few more questions, the interviewer changed the subject.)

I: Just looking at that as a single displacement reaction, can you write products for it?

CS: Cu...what's the charge on the Cu?

I: Copper here (in $CuSO_4$) is a positive two ion, sulfate is negative and zinc is neutral.

CS: So, it would be $CuZn_2$?

The case study was able to recall the E phase demonstration accurately during the post-E discussion, but she was not able to make a clear connection between the G laboratory activity and the E demonstration. During this interview, the case study seemed to organize a considerable amount of information relating to the content of the learning cycle. Misunderstandings and misconceptions still bothered the case study in this interview.

I: Thinking back to the chemical cell (E demonstration--Appendix 7A), what was losing electrons?

CS: I think zinc lost it and it went over to the copper and the copper gained it.

I: Can you relate that back to the lab that you did earlier?

CS: Not really.

I: Let me write down what you added together originally, zinc and copper (II) sulfate, and you look at your products to see if you can relate that back to the demonstration and what you were talking about. You said that zinc lost electrons and copper gained electrons. Does that relate at all to the zinc and copper (II) sulfate that you worked with in the lab?

CS: I think I was wrong because when the zinc is by itself, in its elemental state, it's neutral. Then, it comined with SO_4, which is two minus, so it would be a 2+.

I: How did it get to be a 2+?

CS: It loses two electrons, just like in the investigation, and the copper--it's 2- --gained two because when it's written by itself, it's neutral; so, it's 2- over there (left side of the equation in $CuSO_4$) and it's neutral (on the right).

I: Is it 2- here? (on left)

CS: I think so.

I: Let me show you can equation I showed you on the very first day. (wrote $2Cl^- + Br_2 \rightarrow 2Br^- + Cl_2$) Is that a chemical change?

CS: I think it would be because the chloride atom had a negative charge and it lost the negative charge to bromine. I think it would be a chemical change.

I: Why would it be a chemical change?

CS: It seems like if the chlorine had a negative charge, then, when the products formed, it had a positive charge, it must have lost electrons and since it lost electrons then it would be a chemical change.

I: Is this positive? (referring to Cl_2)

CS: No, it's neutral.

I: Is there an equal loss and gain of electrons?

CS: Yes, so I guess they would both be spectator ions.

I: What is a spectator ion?

CS: It doesn't gain or lose electrons.

I: Did chlorine gain or lose electrons?

CS: Oh, it lost.

I: And, what gained electrons?

CS: The bromine.

I: Is the amount of loss of electrons and gain of electrons equal?

CS: Yes.

As stated earlier, this case study was hampered by misconceptions and incomplete understandings from work that preceded this learning cycle. She seems to have developed a clearer understanding of the role of electron transfer in ion formation and chemical change, as a result of her work in this learning cycle. The post-E interview seemed to serve as a form of "invention" discussion for the case study in that there was apparently a significant amount of information organization that occurred during that interview.

Summary. A review of these case studies encourages some speculation concerning the workings of the learning cycle approach and the connections between the learning cycle approach and the assimilation-accommodation-organization theory of Piaget. Many of these students refer to previous lessons to support statements they made in the pre-learning cycle discussion and in later discussions as well. The information carry-over, especially from Learning Cycle 6, seems to give them a theoretical as well as an observational theory of chemical changes. Applying the rules of LC-6 inflexibly, however, would lead the students to reject certain oxidation-reduction reactions where atom rearrangement is not evidenced. The consequence of this is that the previous knowledge may have a retarding effect on the learning of, or the expansion of, the knowledge taught in LC-8.

Some of the students, nevertheless, still use observational information as the sole justification for identifying chemical changes. Others, however, seem to begin to use theoretical ideas involved with atoms and the rearrangement of atoms and electron structures.

CS-15, who is an extremely good student, seems to go through the assimilation-accommodation-organization sequence in more or less the same order as the learning cycle phases. The post-G interview indicates a knowledge of laboratory material but some confusion. In other words, there does seem to be some assimilation, but an assimilation resulting in disequilibration concerning the concept. The post-I discussion, however, rather than showing a complete accommodation of this concept only showed a partial accommodation. There is still some confusion that is at least not organized with other thoughts. This is evidenced by the students misconception using subscripts. The post-E interview shows a more complete understanding. Total accommodation has occurred by now or perhaps this might be identified as organization taking place. This is evidenced by the utilization of both the atom rearrangement and the electron transfer, in concert, to identify chemical change. In this particular learning cycle the invention discussion alone does not seem to be enough to obtain the sort of accommodation that theoretically one would hope for.

Both case studies 516 and 109, who had been exposed to the G and I phases but not the E phase of the learning cycle, came out of the learning cycle with some acquired language of the concept, but some misconceptions and confusion. From this is support of the necessity of the E phase of the learning cycle.

Evidence for the necessity of the gathering the data phase can be seen in CS-25, who lacked the G phase in his learning cycle. Even at the end of a lecture, which defined oxidation and reduction, there was no accommodation of the concept. By the end of the E phase this student was still using observational rather than theoretical information, although there was some knowledge of the electron transfer idea when it was asked for.

CS-132, who lacked the I discussion (although this group gained a certain amount of information from the E phase) saw no connection at all between the G and E phases.

Across the case studies then there is some evidence of the necessity of all three phases in the learning cycle and some indication that there are connections between the different phases of the learning cycle and the different parts of Piaget's assimilation/accommodation/organization theoretical model.

Achievement Analysis

Only one version of the Cognitive Achievement Test (CAT) was utilized during Learning Cycle 8. The test was given as a pre-test and also as a post-test. The test was furthermore given after the invention discussion in all five experimental groups. Since the invention discussion was the final phase of the learning cycle in classes 16 and 22, and because there was no invention discussion in section 25, this meant that only section 11 and 14 had an intermediate examination. In summary, the CAT test was given as a pre and post-test in sections 16, 22, and 25, and given as a preintermediate, and post-test in sections 11 and 14. The purpose of the intermediate test was to do a trend analysis to see the role of the invention discussion of the learning of students. A copy of this CAT test plus the grading criteria used for grading the student responses can be found in Appendix 7C.

Table 7-8 summarizes the analysis of variance for the pre-test, developmental

TABLE 7-8: LC-8: REDOX REACTIONS

ANOVA for CAT 1 (Pretest), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	144	2.90	0.09	*
Class	4	43.3	0.87	0.48	
Class X Level	4	43	0.86	0.49	
Error	105	49.7			

Least Square Means

Level	CAT 1
concrete	29.8
formal	32.1

formal > concrete

Class	CAT 1
11	32.2
14	30.1
16	31.8
22	28.9
25	31.8

level versus class. As can be seen there is no main effect differentiating the different classes from each other. There is a main effect involving the developmental level with formal students scoring slightly better than concrete students on the examination. In studying the means, which are on the order of 30%, it can be seen that the classes are essentially equivalent to each other insofar as this pre-test is concerned and that also the relative amount of prior knowledge on this concept of oxidation-reduction reactions is slight.

Table 7-9 summarizes the analysis of variance for the post-examinations and the results are similar. Once again it can be shown that there is a main effect for developmental level with formal students scoring higher than concrete students, but no differentiation between groups by class. Studying the mean scores for the different classes, it can be seen that they fall relatively into two groups. Those involving sections 11, 14 and 25, which are slightly higher, but not significantly higher, than section 16 and 22. Sections 16 and 22 both had no expansion phase of the learning cycle. Once again test scores themselves are relatively low, on the order of 40%. This indicates that one of two things, either the students did not learn very much during this learning cycle or the examination that was used was inappropriate. It might be inappropriate because of its difficulty level or the questions might not directly relate to what the students actually learned. Even though the total amount of learning as indicated on this post-test is rather low in comparion with other experiments, there was an average 10 point gain for the classes.

Table 7-10 summarizes analysis of variance for the gain scores going from pre to post-test, development level versus class. Once again there is a main effect differentiation between formal and concrete students, formal students gaining more significantly than concrete students overall. As before that is no statistically significant difference between classes on their gain scores.

TABLE 7-9: LC-8: REDOX REACTIONS

ANOVA for CAT 3 (Post test), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	2708	9.57	0.00[illegible]	*
Class	4	357	1.26	0.29	
Class X Level	4	120	0.42	0.79	
Error	97	283			

Least Square Means

Level	CAT 3
concrete	36.9
formal	47.4

formal > concrete

Class	CAT 3
11	46.5
14	44.3
16	37.4
22	38.3
25	44.4

TABLE 7-10: LC-8: REDOX REACTIONS

ANOVA for Gains (Pre to Post), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	1310	4.87	0.03	*
Class	4	388	1.44	0.22	
Class X Level	4	137	0.51	0.73	
Error	72	269			

Least Square Means

Level	Gain
concrete	7.0
formal	15.4

formal > concrete

Class	Gain
11	14.9
14	15.7
16	3.4
22	10.0
25	11.8

Studying the means it can be seen that section 16 gained much lower numbers of percentage points than the other groups on the pre to post-test measures.

In summary, there is little evidence from this data to indicate the necessity of the various phases of the learning cycle with regard to the other phases of the learning cycle. However, because of the relatively low post-test scores and low percentage gain in learning as measured by the CAT test, there must be some question as to how effective the learning cycle activities or the CAT examinations were in teaching or measuring the concept of oxidation-reduction reactions.

Trend Analysis. An analysis of variance repeated measures design for class 11 and 14 was carried out as a trend analysis as shown in Table 7-11 and 7-12. The trend measured was scores on the CAT examinations as the students in the particular class went from pre-test, post-invention discussion, and to post-test scores. Class 11, which was the control group, which had all three phases of the learning cycle, was given a pre-test, took part in the gathering the data, and invention/discussion phases, was given another test, then took part in the expansion phase and finally given a post-test. Examination of the analysis of variance between these three CAT tests is shown in Table 7-6 and is significant. Examination of the means on the three administrations of the CAT show that the post-test score was significantly higher than the pre-test or the post-invention score. This can be interpreted as showing the necessity of the expansion phase and once again illustrates the importance of this phase to the learning in learning cycles. Since the indication is that there is no real significant difference between the pre-test and the post-invention scores, there must be some question as to what is the role of the invention discussion in this learning cycle at least. Perhaps it's a preparative role which makes the expansion more effective than it would be otherwise.

TABLE 7-11: LC-8: REDOX REACTIONS
Trend Analysis for Class II

Source of Variation	DF	Mean Square	F	P	
CATs	2	1406	8.42	0.0006	*
Error	57	167			

Least Square Means

CAT	Score
1(pre test)	31.9
2(post I)	34.7
3(post test)	47.6

CAT 3 > CAT 1, CAT 2

TABLE 7-12: LC-8: REDOX REACTIONS
Trend Analysis for Class 14

Source of Variation	DF	Mean Square	F	P	
CATs	2	788	3.98	0.03	*
Error	45	198			

Least Square Means

CAT	Score
1 (pre test)	30.2
2 (post I)	36.4
3 (post test)	44.2

CAT 3 > CAT 1

The trend analysis for class 14, which eliminates the gathering the data phase, had a pre-test followed by the invention discussion, which was followed by a post-invention discussion CAT followed by the expansion and, then finally, the post-test. The analysis of variance once again is significant and the examination of the means using the Newman-Keuls shows that the post-test is significantly greater than the pre-test score. The role of the invention, however, is ambiguous in that there is no indication as to whether it is greater than the pre-test score or less than the post-test score.

Attitude Analysis

The BAR attitude inventory was administered to each of the five experimental groups at the conclusion of Learning Cycle 8. The results of an analysis of variance between classes for the contentment and comprehension factors of the BAR analysis are summarized in Table 7-13 and 7-14. As can be seen from those analyses there is a significant difference between classes for each of these factors. For the contentment factor groups 16 and 22 are greater than classes 11, 14 and 25. In other words, this factor seems to divide the classes into two major groups with group 16 and 22 being greater than groups 11, 14 and 25. A study of these groups indicates that the higher rated groups had no expansion phase whereas those groups that were rated lower had expansion phases.

A study of the comprehension factor is similar if not exactly the same. In this analysis, groups 16 was greater than 11, 14, or 25, with group 22, although rated second highest not having a significant effect. Taken together, however, it seems as though the E phase resulted in lower attitudes both in the students contentment toward this learning cycle and in terms of their feelings of comprehension of the concepts of oxidation-reduction reactions. It might be pointed out that this trend is exactly the reverse of what was found in Table 7-9 when the post-test CAT scores are compared. In this particular comparison

TABLE 7-13: LC-8: REDOX REACTIONS

ANOVA for BAR Contentment Factor

Source of Variation	DF	Mean Square	F	P	
Class	4	128	4.18	0.004	*
Error	95	30.6			

Least Square Means

Class	Contentment	
11	25.4	
14	23.7	
16	28.8	16 > 14, 25, 11
22	29.1	22 > 14, 25, 11
25	24.2	

TABLE 7-14: LC-8: REDOX REACTIONS

ANOVA for BAR Comprehension Factor

Source of Variation	DF	Mean Square	F	P	
Class	4	79	3.40	0.01	*
Error	96	23.3			

Least Square Means

Class	Comprehension	
11	28.6	
14	28.6	
16	32.9	16 > 11, 14, 25
22	31.3	
25	29.3	

the classes 16 and 22 scored lower than the classes 11, 14 and 25, although this was a non-significant result statistically.

As far as the comprehension factor is concerned it might be hypothesized that the addition of the expansion phase resulted in a less clean-cut look at the concept being stressed in oxidation-reduction reactions. The students may have identified this as being a new concept rather than an expansion of their knowledge. On the other hand sections 16 and 22 ended with the invention phase which may have appeared more clean to the students and given them the idea, whether false or true, that they had a better understanding of the concept.

The hypothesis with the contentment factor may have more to do with the nature of the expansion itself. The students may have found the expansion particularly confusing or boring or uninteresting compared with the activities associated with the gathering the data or invention phase. The expansion consisted of a demonstration rather than a regular student directed laboratory, readings and questions associated with readings.

The written comments found on the reverse side of the BAR (tally sheets can be found in Appendix 7D) support in part the feelings of negativeness toward the readings that were found in the expansion. Negative comments concerning the readings were found in classes 11 and 14. Comments concerning the difficulty of the reading questions can also be found in classes where the expansion was utilized. Positive comments concerning the laboratory in the G phase are found in all classes with the exception of section 14 which, of course, did not have the G phase.

Conclusions

Low post-test scores found on the CAT analysis lead to two possible explanations for this learning cycle. (1) That the CAT examinations themselves were too difficult and, therefore, the CAT analysis results are ambiguous, or

(2) that the students did not learn the material associated with the learning cycle activities. From the CAT scores themselves and the end of the class discussion by the principle investigator and two participating teachers, there is some indication that the test itself may have been too difficult. The students spent a long time taking the examination, indicating that they thought they had plenty to say. Nevertheless the results were disappointing. An independent test given by the instructors led them to the conclusion that the students' learning of this concept was incomplete at the conclusion of the learning cycle activities. The best guess would be that both factors are influencing the data that was collected in this particular learning cycle.

Another problem indicated by the post-experiment discussions indicated that there is a large amount of carry-over from Learning Cycle 6 and Learning Cycle 7 into the learning that occurred in this learning cycle. Since the experience of the students in Learning Cycle 7 was differentiated (because it was also used as an experiment) students may have come into Learning Cycle 8 with different background experiences which may have influenced their learning in this particular learning cycle.

There is evidence for the necessity of all three phases in the case study information. Especially there is evidence of key role for the expansion phase of the learning cycle. This is found in CS-15 especially.

The post-test CAT analysis indicates no differences significantly. This argues for no necessity of the phases. There is some minimal evidence indicating a favorable trend toward those phases that had the expansion, although this evidence is at a non-significant level. There is some indication from other data indicating that the expansion may, in fact, act as a mini-learning cycle where students force all three phases, even though all three phases are not available to them in the activities. The trend analysis also argues for an expansion phase or combination of the invention and the expansion. This result is also supported by the experience with CS-15 where it seemed that the combination of the I and E phases resulted in the learning that this particular student gained from the learning cycle.

Interestingly, the sections which did not have an expansion phase seemed to have a better attitude toward the learning cycle than students who did. This leaves us with the tentative conclusion that the students seem not to like have the expansion phase for this learning cycle, although it may have helped them learn the material.

Several rationales for the BAR results come to mind. Perhaps for the students the GI phases combination seem complete and seems to offer an easy to understand concept. Adding the expansion may expand their knowledge of the concept, but it may also seem to be confusing. Since there were no actual student led experiments in the expansion, students may have found the expansion itself to be not as enjoyable as other parts of the learning cycle.

CHAPTER EIGHT

LC-10: RATES OF REACTION

A "DATA PRESENTATION" FORM EXPERIMENT

Experimental Design

LC-10 was designed to teach the concept of rate of chemical reactions. Originally the learning cycle activities were utilized to demonstrate the effect of catalysts. As developed and implemented, however, the effect of amount of reactant also was developed. As a consequence two concepts are central to this learning cycle: (1) A catalyst is a substance which speeds the rate of a chemical reaction without itself undergoing a net change, and (2) The amount of a reactant (including a catalyst) affects the rate of a reaction. The second concept was developed during the expansion phase of the learning cycle and was, therefore, not developed during the invention phase.

LC-10 was designed as a "data presentation" form experiment. Although there were several other form experiments (See LC-7 and LC-14), this is the only "data presentation" experiment. In manipulating the form variable in those other learning cycles, the form was kept consistent from one phase to another. If, for example, reading was the form being studied, then readings were developed and utilized for all of the activities of all of the phases of the learning cycle. It was felt the most information concerning this form could be gained in this way. It was also felt that although these experiments were useful for research purposes, they were artificial and did not resemble normal classroom practice. In the "data presentation" form the variable was only treated in those phases that presented data to the learner (the G and E phases). The invention phase was similar for all groups and consisted of a group discussion. For example, the reading group (class 11) utilized readings whenever data was presented to the students. The sequence of all of the phases remained constant. This more nearly approaches normal classroom procedure. Table 8-1 summarizes the assignments for the five groups utilized for the experiment. Notice that there are two control groups. Control group 1 (class 14) utilized readings in the exploration phase in addition to the experimental activities. This was the curriculum materials as they were originally written. In control group 2 (class 25) readings were eliminated. This allowed a more consistent "data presentation" form. The control 2 group utilized the laboratory to present the data and was, therefore, another experimental group.

Two nonequivalent forms of the CAT were developed for evaluating the learning cycle. Form A was used as a pre-test to check for prior knowledge of the concept. Form B was used as a post-test and was given six weeks after the post-test as a retention test.

TABLE 8-1

LC-10: Group Assignments

Class	Variable Assignment
11	Reading
14	Control 1
16	Demonstration
22	Discussion/Lecture
25	Control 2

Description of Classroom Activities

Since LC-10 was a form experiment in which the form of data presentation was the variable, each of the classes was exposed to all three phases of the learning cycle in order; gathering data (G), invention (I), and expansion of the idea (E). Six sections were involved in this test; two as control groups and the other four with variations in data presentation form. One section, called Control 2, differed from the control groups only by the omission of the

TABLE 8-2

Learning Cycle Activities for LC-10

	Control 1 14	Control 2 22	Demonstration 16	Reading 11	Lecture/ Discussion 25
G	Students collect data	Students collect data	Teacher collects data in class with no student help	Students read a presentation of data	Teacher orally presents data (collected previously)
I	Class Discussion	Class Discussion	Class Discussion	Class Discussion	Class Discussion
E	Students collect data; Reading; Discussion; Problems/ questions	*Students collect data; Discussion; Problems/ questions	*Teacher collects data in class with no student help; Discussion; Problems/ questions	Reading; Discussion	*Oral description of experiments and data; Discussion; Problems/ questions

*Note the absence of the reading in the "E" phase of these groups.

reading in the E phase.

The remaining test groups were presented data from teacher demonstration, from reading about data, and from oral presentations of data in a lecture/ discussion format. These forms were employed during the G and E phases, where students would normally generate data from laboratory work. The I phase, in all sections, remained as a teacher directed class discussion of the G phase data, generated by the various means.

Table 8-2 summarizes the progress through the learning cycle for the sections involved in this test.

Classroom materials, with the exception of the E phase reading, are included in Appendix 8A. The E phase reading assigned was a chapter on catalysis in the book Asimov on Chemistry, by Isaac Asimov. The specification of classroom activities by test and class days is summarized in Table 8-3. Appropriate appendix page numbers are given in parentheses.

TABLE 8-3

LC-10: Classroom Activities

Section / Day	Control 1 14	Control 2 25	Demonstration 16	Reading 11	Lecture/ Discussion 22
1	Begin G laboratory (8A-2 through 8A-4)	Begin G laboratory (8A-2 through 8A-4)	G Demonstration (8B-2)	G Reading (8A-7, 8A-8)	G Lecture (8B-6)
2	Complete G and do Idea Questions	Compete G and do Idea Questions	I Discussion (8B-4, 8B-5)	I Discussion (8B-4, 8B-5)	I Discussion (8B-4, 8B-5)
3	I Discussion (8B-4, 8B-5)	I Discussion (8B-4, 8B-5)	E Discussion 8A-9, 8A-10)	E laboratory Reading (8A-9, 8A-10)	E laboratory Lecture (8B-6, 8B-7)
4	E laboratory (8A-5, 8A-6)	E laboratory (8A-5, 8A-6)	Graph E Laboratory Data; Discuss	Graph E Laboratory Data; Discuss	Graph E Laboratory Data; Discuss
5	Graph E Laboratory Data; Discuss	Graph E Laboratory Data; Discuss	-------------	E Reading	------
6	E Reading	----------	-------------	-----	------

Post Experiment Discussion

At the conclusion of the activities of learning cycle 10 the two teacher participants and the principal investigator had a discussion to compare and discuss observations from the classroom, from case study interviews, and general attitudes and observations concerning the nature of the learning that took place during the learning cycle activities.

Since learning cycle 10 was a form variable experiment, some of the discussion which took place concerned itself with the form or format of the data presentation in various parts of the experiment. The teacher whose classes had the presentation of data by reading and by demonstration, complained about the formats. She said, "Demonstration is obviously better than reading but both of them leave so much to be desired." When asked to explain why she felt that way she said that there was "a lack of interest, a frustration on the part of the students, a belligerence on the part of many, a total turn off on chemistry. They can't even tell you what system you are talking about. They don't know if they have ever seen it or talked about it." This teacher admitted that her attitude toward the reading was as negative as her students!

The other teacher related some feeling about the lack of learning or learning difficulties which occurred in some of the experimental groups. He related a feeling that students who did not do the laboratory experiment seemed to have a lot more difficulty in keeping track of the information and facts than the students who had actually done the laboratory experiment. This seemed especially, to him, to show up during the discussion sessions which were held. When the data were graphed in the expansion phase of the learning cycle, the instructor felt that the students didn't know that it was oxygen amounts that were being graphed. "They drew the graph but had no idea of what it represented." In remarking on one of the case studies, one of the teachers said, "He was able to interpret the graph just fine but he didn't know what it represented. He didn't have the slightest idea that it was the same system that he had looked at before. He didn't have an idea that it was the manganese dioxide/hydrogen peroxide reaction again. The graph was a complete abstraction to him. Although he was able to deal with the abstraction in a fairly reasonable way, he didn't get connected with the specific data that had been discussed earlier." In remarking about the reading group one of the teachers related that, "They read it and you say 'Are there any questions?' but they have no idea what to ask any questions about. There was nothing for them to grab ahold of, and I think that that is why the interest drops. As far as they are concerned they haven't really done anything." Both teachers felt that part of the reason was that students have great difficulty getting information from technical reading.

There was some discussion that this particular unit might belong in a different place in the overall curriculum. It was felt that it might better fit close to a unit on activation energy where concentration effects are discussed.

The difficulty level of the concept concerned with this learning cycle was discussed and how that concept was related to the CAT examinations which were designed for use with this learning cycle. One of the investigators said, "One of my reactions to this after we had gotten into it, especially after I tried to talk to the case study's about the concept, was that to a large extent this is a pretty easy concept and we may not see any differences between the various experimental groups mainly because it's hard to ask a question that goes below the superficial. Then again the quiz that we had I thought was pretty tough." The other instructors agreed that they also thought that the quiz was fairly difficult, but that they received a different impression when talking with some of their students. "They sure didn't take very long on it," said one of the instructors. Not even my most meticulous student. I was amazed. In fact, I told the first class that I gave it to that this was going to take them a while to do it and that it would be pretty difficult. One of my students, who is not one of my better students, came up to me about ten minutes later and said, 'I must be missing the point, this is easy.'" Both teachers agreed, however, that the pre-test was very difficult for the students with lots of them turning in blank papers.

One of the instructors said that he found it very difficult to talk about these concepts with their case studies. He said, "I had more difficulty with this one than I did the others and part of the problem was that it seems difficult to talk about catalysis except on a superficial level. The only thing I could really say to them was, 'What is a catalyst?' and then I often received this memorized answer and felt dissatisffed with it. I wanted to ask them some penetrating question to find out if they really knew what a catalyst was, but I couldn't think of any questions to ask."

One of the instructors expressed doubt about the ability of the tests that we used coming up with any identifiable differences between groups. He felt that the students who did not have the chance to generate their own data and experience working with the apparatus in the experiment would be at a disadvantage in learning and identifying the phenomenon associated with catalysis. He did feel, however, that these differences might be intangible and that as consequently might be very difficult to see the differences between these students. Part of this may be a continuation of the idea that the questions that we're asking are on a very superficial level and the differences between the group may be on a much deeper level.

Another concern about the experiment was raised in regards to the difference between experimently derived data and data that was cooked up for the purposes of demonstrations and discussion and reading formats. One of the class observers related the following. "One of the things I did notice from my case studies, and also my observations in classes, is that there is a major difference between data that we generate as instructors and data that students generate themselves. That is, that the data we generate is more accurate. You don't have as much garbage to work with. Most of the time this doesn't seem to make much difference if the data that is collected is fairly clear cut, but in the case of the catalysis information, some of the data required a lot of interpretation. Originally we generated four sets of data that we used for the lecture, for the reading, and for the demonstration. In the demonstration we only used one set of the data and there was only one data point that they were looking at. That one data point had a weight difference for the catalyst before the experiment and after the experiment of only .01 gram. Nobody had any trouble at all seeing that those numbers were exactly the same and that the catalyst was not used up during the experiment. However, in some of the other classes we had a variety of weight differences that were larger than that. These differences were still less than one percent. But the students really got involved in the whole mess of trying to figure out where the weight went. As a consequence they came up with a lot of alternatives, possibilities that confused them, at least partially, on the concept. With this group, then, there's still going to be a persistent kind of non-understanding of experimental error." Because the pre-prepared data that was used had been generated by the project staff during the development of these laboratory materials the previous summer, there was some concern that the data that was developed by the students in the control group was of a lower quality. This is especially true for the expansion phase where different concentrations of catalysts were used in order to see what the effect of these would be on the rate of the chemical reaction. Some of these experiments behaved poorly during the actual learning cycle. The graphs were "not as neat as the graphs that we had last summer." One of the instructors indicated that her graphs didn't come out the way that they should have and as a consequence made the discussion of the concept much more complicated. Considering the variables the teachers didn't think that the data was all that bad, but there's no denying that the pencil and paper data was much closer to theoretical expectations in comparison. There was some concern that this poor data might affect the nature of the students' attitudes associated with Learning Cycle 10.

Case Studies

One student was chosen at random from each of the five experimental classes to serve as a case study. These students were interviewed before, during, and after the learning cycle activities, and were asked questions regarding their understanding of the concept being taught. Although the students themselves were not necessarily representative of the experimental group to which they belonged, it was felt that these case studies, along with observations and other types of information would give us insight into learning occurring during the learning cycles, and might help to explain some of the phenomenon we observed.

Case Study 502. The teacher described this case study as an interested, intelligent student. He would participate in the classroom activities, ask thought provoking questions, and as a consequence gain an understanding of the material. His schedule included other courses which required a large amount of work outside of the classroom. If there was a gap of time where the case study had completed his chemistry assignment, you would find him doing the homework for his other classes. This pattern of behavior did not seem to affect the case study's work in chemistry. A profile of CS-502 is found in Table 8-4.

Learning Cycle 10 was a "Data Presentation" form experiment. The case study was in the reading group. In a regular learning cycle, data is collected by the student during two phases: the gathering data (G) phase and the expansion (E) phase. For the reading group the data and a description of the method of collection were given to the student through a reading format. The invention (I) phase was conducted as a teacher led discussion, the same as the control groups. There were four interviews scheduled with this case study: a pre-learning cycle (pre-LC), a post-gathering data (G), a post-invention (I), and a post-exapnsion (E) interview. The purpose of the interviews was to determine the case study's understanding of the concept of the learning cycle at the various stages mentioned above. The central concept of learning cycle 10 was that catalysts are substances that increase the rate of reaction, are not used in the overall reaction, and do not cause the reaction. Excerpts from the case study tape will be used to demonstrate points made in the summary of each interview. I will be used to designate the questions by the interviewer and CS the responses by the case study. Each interview centered around two questions: (1) What is a catalyst and how does it work? and (2) a discussion of the data.

During the pre-LC interview the case study says a catalyst is a chemical substance that is added to a chemical reaction, but he doesn't know why it is added. The pre-test (Appendix 8C) for this learning cycle asked the student to list three ways in which to speed up a reaction. The case study listed heating and stirring as two ways to accomplish this. He had a very interesting misconception concerning the effect of heating and stirring on a chemical system.

I: Have you ever heard the term catalyst used before?

CS: Kind of.

I: Can you give me a definition of catalyst in your own words?

CS: A substance, chemical, that's added for a chemical reaction.

TABLE 8-4

CASE STUDY PROFILE

Student	502				Variable	Data Presentation
Sex	M				Group	R
Class	11				LC 10 test scores (unadjusted)	
Grade Level	11th					
Birthday	03-18-65				CAT 1	33 %
I.Q.	124				CAT 2	78 %
GEFT[1]	16	(Quartile 4)			CAT 3	99 %
VH[2]	5					
FR[3]	5	6				
CC[4]	5	6				
Grades[5]	A	A	A	A		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

I: Why do you add it?

CS: I have no idea.

I: You had a quiz this morning. Tell me in your own words what that quiz was asking?

CS: It asked three ways to speed up the reaction between zinc and copper sulfate.

I: What did you put?

CS: I said heat and stirring it. I didn't put a third one.

I: How do those things speed up the reaction?

CS: It causes the electrons to move faster which makes it easier to lose or gain electrons.

I: How do they move faster? I'm not sure what you mean.

CS: The speed at which they are going around the nucleus. When they speed up, that's when they are lost.

I: And heating them up causes them to do this?

CS: To move faster.

I: How does stirring speed up a chemical reaction?

CS: The vibrations cause them to move around and speed up.

During the post-G interview the case study's definition of a catalyst had changed. Now he knew the purpose of adding a catalyst to a chemical reaction. The case study recognized that the catalyst (MnO_2) for the reaction described in the G reading was not changed. He was really thinking about the experiment and using information concerning physical properties from the G reading to rationalize that MnO_2 was not produced. After the laboratory activities, the students answered the idea questions (Appendix 8A). Following this individual work, the students were asked to form small groups and to discuss the idea questions. During these small group discussion the case study benefited from the past experience of other students.

I: Did you get your psychology homework done?

CS: Yeah.

I: Can you tell me what you did today?

CS: We were given a reading which explained a chemical reaction between MnO_2 and H_2O_2. It gave the results of the reaction and the weights. Next we had two questions to answer: (1) Find the percentage weight change and (2) Describe the products and write an equation for the reaction.

I: What conclusions did you draw?

CS: The percentage weight change was - .14%. A gas was produced. It was oxygen. The flammability test was run. The product was the same as the reactant. It was MnO_2 with the same characteristics and really close to the same weight. .01 of a gram is not a very big weight change.

I: What did the weight change mean?

CS: It was such a small weight change it could be attributed to an error with the balance or it was taken off with the glass rod that was used in it. We said the products were oxygen, manganese dioxide and water. These came from the manganese dioxide and hydrogen peroxide.

I: You said you got a very, small, and insignificant weight change. How can that be if oxygen was one of your products?

CS: The oxygen came from the H_2O_2. Doesn't H_2O_2 naturally produce water and oxygen?

I: What makes you think so?

CS: After a long time it doesn't work when you pour it on a cut.

I: You are saying the oxygen came from the...

CS: H_2O_2. The MnO_2 only helped speed up the reaction.

I: How does it do that?

CS: Good question. I don't know it does. That's what a catalyst is.

I: That's what [illegible] catalyst is?

CS: Isn't it a reactant that helps speed up a reaction but doesn't change itself like MnO_2?

I: Where did you get that idea?

CS: Through the discussion.

I: Who?

CS: Someone else in the class and Mrs. Atkinson.

I: Did you have this idea before or is this brand new to you?

CS: I have heard of catalyst before but I didn't know what it meant. In the small group discussion, they said MnO_2 was a catalyst.

I: Who said?

CS: The other people in the group.

I: You originally wrote down this equation: $H_2O_2 + MnO_2 \rightarrow H_2O + O_2 + MnO_2$, and you balanced it. Did you change that reaction any when you talked to the group?

CS: No.

I: Early in the hour when you were working at your desk alone, I overheard you talking to the guy in the desk in front of you. You were talking about a substance, MnO. What was that about?

CS: I was wondering if the oxygen might come from the MnO_2 and changed it to MnO. I ruled out that.

I: Why did you do that?

CS: For it to become MnO the Mn would have to go from +4 to +2. I decided it would change the substance. MnO would be a different substance than MnO_2. I didn't know if it would have different characteristics or not. The substance left had the same characteristics as MnO_2, so I decided it (O_2) probably came from the hydrogen peroxide.

During the post-I interview the case study used information from the invention discussion to answer the questions. His definition of a catalyst had been refined since the post-G interview.

I: Describe in your own words what you did today in class.

CS: We discussed the reaction of $MnO_2 + H_2O_2$. We ruled out the possibility of it being MnO left in the flask, because the atomic weight percentage was too high.

I: How do you know if it is too high or too low?

CS: The percentage weight change using atomic weights should equal the percentage weight change in lab weights. If the substance was MnO, the percentage change with atomic weights would be - 18.3%. The actual percentage weight change (lab weights) was .14%. That's too high.

I: That is quite a bit of difference. What if only part of the MnO_2 reacted?

CS: Wouldn't the percentage weight change still be too high?

I: Would you expect it to be - 18.3% still?

CS: I don't think it would be that high. I think it would be more than .1%.

I: You talked about the reaction in class today. What did you decide?

CS: The H_2O_2 changed to H_2O and O_2 gas. MnO_2 speeded up the reaction. H_2O_2 would react by itself.

I: If H_2O_2 will react by itself, why do you add the MnO_2?

CS: To speed up the reaction so you can observe it.

I: How does it do that?

CS: Good question.

I: What is a catalyst?

CS: A substance that speeds up a chemical reaction but doesn't change.

The case study demonstrated in the post-E interview that he was developing an understanding of the material. His memory of what had been done in class was very poor. The expansion activities included graphing and interpreting the data presented to the students through a reading format. The case study was able to interpret the graph and draw conclusions about the system from this information. During this interview he accommodated the fact that the amounts of reactants affects the rate of reaction. He retained his earlier misconception concerning the effects of heating on the electrons of a substance. This is not surprising, however, there was nothing in this learning cycle to challenge this idea.

I: Why don't you start out and describe for me what you did yesterday?

CS: What did we do yesterday?...Oh, we read a reading is Isaac Asimov. It described catalyst...I know we did something else...Do you know what we did?

I: What kind of a graph did you get when you graphed that data?

CS: It started out going up steep and then curved to less of a slope. The more catalyst you had the more oxygen that was produced in the five minutes.

I: So, you had a graph that looked something like this? Interpret the graph for me.

CS: The graph is time in relations to how much O_2 was produced. In the first few minutes there is more O_2 produced, then as the time goes by it is still producing oxygen but at a slower rate.

I: So, there is something affecting the rate of the reaction. What is it?

CS: The catalyst. The more catalyst you had the more O_2 that was produced.

I: You have added another line to the graph.

CS: If there is less of the catalyst, the line will have the same general form and there was less O_2 produced.

I: How do you account for the shape of either line?

CS: It starts out producing a lot of O_2. As time goes on, O_2 is being used up, so there would be less.

I: You say O_2 is being used up, by what?

CS: By chemical reaction--O_2 is being made into a gas (that's the volume of gas). As it is being produced it is being taken out of the solution so as there is more O_2 produced there is less in the solution so the rate of O_2 production is decreased.

I: How can you account for the decrease in the rate of reaction?

CS: The amount of the reactants.

I: What are the reactants?

CS: The H_2O_2, so as the amount of reactants decreased there is less to react.

I: Where did you get that idea?

CS: It was mentioned in class and put on the overhead. After talking about it, I just thought of it.

I: You didn't have the idea before you came in here?

CS: Yeah, she had mentioned it, but it just now registered as affecting the rate. I guess it sort of just came out of my head. I realized the amount of reactants affects the reaction.

I: Summarize what causes a chemical reaction to speed up and why.

CS: A catalyst speeds up a reaction and I really don't know why. The amount of reactants--the more reactants the faster the chemical reaction will occur.

I: Why?

CS: There's more to work with--there's more to be produced. As these reactants are being turned into products, there will be less reactants so the rate will decrease.

I: Why does heating affect the rate of reaction?

CS: Heating causes the electrons to become more active and easier to be gained and lost.

I: What about stirring?

CS: Stirring causes vibrations which causes the
electrons to be more active.

In summary, the case study had a poor memory of the activities of this lesson. However, he did not seem to be penalized for the reading format of the lesson. Being formal and field independent (See Table 8-4) he was able to obtain the information that was needed from the readings. The case study had a good understanding of the concepts on Learning Cycle 10.

Case Study 13. The teacher described this case study as an interested, involved student who had set some expectations of herself. One of these expectations was that she should make an A in chemistry. The case study would become involved in the classroom activities and finish the assignment but very often resist thinking through the material for the answer. A profile of CS-13 is found in Table 8-5.

Learning Cycle 10 served as a data presentation form experiment. The case study was in class 14 which was the control test group. They went through a regular learning cycle which consists of three phases: a gathering data (G) phase, an invention (I) phase, and an expansion (E) phase. The test group carried out each phase as it would normally be controlled. The G phase is a laboratory activity, the I phase is a class discussion of the data collected during G, and the E phase consisted of a related laboratory activity and a reading. There were four interviews scheduled with this case study: (1) pre-learning cycle (pre-LC), (2), post-gathering data (post-G), (3) post-invention (post-I), and a (4) post-expansion (post-E). The interviews were to determine the case study's understanding of the concept at the various points in the learning cycle. The central concept of learning cycle 10 was that catalysts are substances that increase the rate of reaction, are not used in the overall reaction, and do not cause the reaction. There were two parts of each interview. The case study was asked to discuss how a catalyst works. Secondly, the student

TABLE 8-5

CASE STUDY PROFILE

Student	13			
Sex	F			
Class	14			
Grade Level	11th			
Birthday	05-10-65			
I.Q.	120			
GEFT[1]	12	(Quartile 3)		
VH[2]	3			
FR[3]	3	4		
CC[4]	5	5		
Grades[5]	A	A	A	A

Variable Data Presentation

Group Control

LC 10 test scores (unadjusted)

CAT 1	67 %
CAT 2	67 %
CAT 3	33 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

was asked to discuss the data. Excerpts from the case study interview tapes will be used to illustrate the summaries of the interviews. I will designate the questions by the interviewer and CS the responses by the case study.

During the pre-LC interview the case study discussed the different types of chemical reactions that have been studied in class.

I: What happens when a chemical change takes place?

CS: The form changes and you end up with different substances as products.

I: What types of chemical changes have you studied?

CS: Single displacement, double displacement, synthesis, and decomposition.

I: What about oxidation-reduction?

CS: It is a reaction where one substance loses electrons and the other substance gains electrons.

I: What is oxidation?

CS: That's when a substance loses electrons.

The post-G interview was not held due to a conflict in the student's schedule.

During the post-I interview the case study knew the definition of a catalyst. When asked about her responses in the pre-test (Appendix 10C) she discussed the effect of the amount of reactants on the rate of the reaction. Her theoretical ideas are rather confused.

I: Before the lab you were given a pre-test which asked you ways to make a reaction go faster. Do you remember what you put?

CS: Add more H_2SO_4 to less zinc, or heat it. That's all I put.

I: Do you know any other way to speed up a reaction?

CS: Now, I do. Add a catalyst.

I: What is a catalyst?

CS: It is a substance you put in to speed up a reaction but it doesn't take place in the reaction.

I: What do you mean doesn't take place in the reaction?

CS: It doesn't react.

I: So, why does it have to be there?

CS: To speed it up. The reaction would happen anyway whether the catalyst was in there or not.

I: Do you have an idea why it speeds up the reaction?

CS: No.

I: You mentioned heating a system to speed up the reaction. Is heat a catalyst?

CS: Yeah, I guess it would be except heat isn't really a substance.

I: The first way you mentioned to speed up a reaction was to increase the amount of sulfuric acid and decrease the amount of zinc. Would you explain that?

CS: If you had a lot of zinc and just one drop of sulfuric acid, you wouldn't notice it happening. But, if you put one piece of zinc and cover it with sulfuric acid it will react more, because more surface area is covered by the sulfuric acid.

I: What does covering more surface area do to speed up the reaction?

CS: It touches more of the zinc. If you just have one drop of sulfuric acid and all that zinc only a little bit of the zinc is going to react. It might be such a small amount you wouldn't see it.

I: Are you saying for the reaction to happen the reactants have to come together so the more reactants that come together the faster the reaction will be?

CS: Yes, if you have more of one thing than the other the same reaction will happen but it is just more noticable.

I: If you had a lot of sulfuric acid and a lot of zinc would it go faster than a lot of sulfuric acid and a little zinc?

CS: Probably the same.

I: Are you saying if you increase one it should be the liquid part. The solid part after a certain point wouldn't make any difference?

CS: Yes.

The post-E interview was not available. Due to the incomplete records of the interviews with this case study, it was difficult to draw any conclusions of the effects of the learning cycle on her understanding of the concept. It was obvious that between the pre-LC evaluation and the post-I interview that she had obtained some knowledge of a catalyst.

Case Study 40. The teacher described this case study as a very intelligent student. He was capable of thinking about the more formal aspects of the course. Many times during class discussions he would ask questions beyond the normal scope of the material. His plans are to attend Berkeley. A profile of CS-40 is found in Table 8-6.

Learning Cycle 10 was a data presentation form experiment. The test group the case study was in was the demonstration group. That is, in a regular learning cycle the student would collect his own laboratory data during the gathering data phase and the expansion phase; however, in this group the laboratories were done by the teacher as demonstrations. The invention phase was a teacher-led discussion. There were four interviews scheduled with this case study: (1) a pre-learning cycle (pre-LC) interview, (2) a post-gathering data (post-G) interview, (3) a post-invention (post-I) interview, and (4) a post-expansion (post-E) interview. The interviews were to determine the case study's understanding of the concept at the various point of the learning cycle. The central concept of learning cycle 10 was that catalysts are substances that

TABLE 8-6

CASE STUDY PROFILE

Student	40				**Variable**	Data Presentation
Sex	M				**Group**	D
Class	16				**LC** 10	test scores (unadjusted)
Grade Level	11th					
Birthday	10-11-65				**CAT 1**	33 %
I.Q.	150				**CAT 2**	99 %
GEFT[1]	18	(Quartile 4)			**CAT 3**	99 %
VH[2]	5					
FR[3]	6	6				
CC[4]	6	6				
Grades[5]	A	A	A	A		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

increase the rate of reaction, are not used in the overall reaction, and do not cause the reaction. Excerpts from the case study tape will be used to demonstrate points covered in the summary of each interview. I will be used to designate the questions by the interviewer and CS the responses by the case study.

During the pre-LC interview the questions centered around defining a chemical change and types of chemical changes. The case study seemed to have some difficulty defining a chemical change, so he relied on observational evidences. He listed four types of chemical reactions without hesitation and gave descriptions of them.

I: What is a chemical change?

CS: A change that can't be reversed--a change that can be seen readily as opposed to changes that aren't as easy to see.

I: What kind of change would you look for to indicate a chemical change?

CS: Change in color, texture, or weight.

I: What are the different types of chemical reactions we have studied?

CS: Double displacement, synthesis, single displacement, and decomposition.

I: Can you give me an example of a decomposition reaction?

CS: I don't really remember any reaction, but it is when something breaks down.

I: Is this when something goes from more complex to less complex?

CS: Yes.

I: What about a synthesis reaction?

CS: That's when you put two substances together to make a complex molecule.

I: What does oxidation mean to you?

CS: It has to do with taking away electrons.

I: Is it possible to have an oxidation with a reduction?

CS: Everything we have studied so far says the electrons have to go somewhere. In the battery set-up the electron had to go somewhere or it wouldn't occur.

The post-G interview concentrated on the case study's knowledge of a catalyst.

I: Have you ever heard of the term catalyst?

CS: Yeah.

I: What does it mean to you?

CS: In chemical terms it is something that speeds up a reaction or makes it happen faster. I think that's what we learned in the seventh or eighth grade.

I: So, that is where you have heard of it before?

CS: Yes.

I: Do you know anything else about a catalyst?

CS: I have always thought it was something that speeds things up so they meet together faster.

I: When things are going to change chemically, do they have to get together?

CS: Yeah, if you move them around more they will get together faster so they will react faster.

I: Do you think your definition of a catalyst might work that way?

CS: Yes.

I: If you had a reaction which involved a catalyst, how would you write that in?

CS: On the arrow between the reactants and products. You are not adding a reactant but you are adding something to speed it up.

I: Could heat be a catalyst?

CS: Yes.

During the post-I interview the case study indicated that heat could not be a catalyst. He was basing his statement on the definition of a catalyst that was given during the invention discussion. The definition stated that a catalyst is a substance; therefore, the case study said heat could not be a catalyst.

The case study was asked questions about his responses on the pre-LC CAT test during the post-E interview. Also, he was asked to state what he knew about catalysts.

I: The question asked for ways to speed up a reaction. Do you remember what you put?

CS: One was to stir up what was involved in the reaction. Another one was to heat, and the third one was to break up whatever was going to react so more surface area would be exposed.

I: Explain to me how each of those methods would speed up a reaction.

CS: Heating it moves them around so they hit each other more so more reactions can occur. Stirring it will have the same effect. Breaking them up will expose more molecules to react.

I: It wounds like you are saying collisions have a lot to do with reactions.

CS: Yeah.

I: Tell me everything you know about a catalyst.

CS: A catalyst speeds up a reaction, more of it will make the reaction occur faster. I still don't know how it works. I guess it somehow pulls the particles together in the same way heating and stirring it does.

I: They actually make them come together faster than they normally would.

CS: Yeah.

I: Is it involved in the reaction?

CS: It is involved in the speed, but it is not a reactant or product.

In conclusion, there are two ideas concerning catalyst that the case study accommodated during Learning Cycle 10. The first one is that since heat is not a substance, it cannot be a catalyst. And, secondly, in the expansion he learned that the amount of a catalyst used affects the rate of reaction.

Case Study 106. This student was described by his teacher as being very quiet, attentive, and business-like in his classroom behavior. He did well on written work, but he only participated in class discussions when directly asked a question. This student transferred into the school after the first nine-weeks period, and his exposure to chemistry content, in his former school, had been more traditional in nature. A profile of CS-106 is found in Table 8-7.

The experiment performed in Learning Cycle 10 was data presentation form experiment. The section, of which this case study was a member, had data presented in the form of a teacher lecture/discussion. All three phases of the learning cycle were performed (gathering data-G, invention-I, and expanding the idea-E). Four interviews were taped with this case study, and they will be described in what follows. These interviews were pre-learning cycle (pre-LC), post gathering data (post-G), post-invention (post-I), and post-expanding the idea (post-E). When dialogue is presented in the following discussion, the I stands for the interviewer and the CS for the case study.

The major thrust of the questioning was to ascertain the student's understanding of the concept of catalysis.

The pre-LC interview revealed that the case study had heard the term "catalyst", but he had not accommodated any structure for the concept.

I: Have you ever heard of a catalyst before?

CS: Yes, but I'm not sure what it is...I've just heard it...on some documentary on T.V.

The presentation of data about the reaction had no apparent effect on the case study with reagrd to the concept of catalysis as was revealed on the post-G

TABLE 8-7

CASE STUDY PROFILE

Student	106				Variable	Data Presentation
Sex	M				Group	D/L
Class	22				LC 10	test scores (unadjusted)
Grade Level	11th					
Birthday	10-31-65				CAT 1	33 %
I.Q.	-				CAT 2	78 %
GEFT[1]	-	(Quartile ____)			CAT 3	78 %
VH[2]	-					
FR[3]	-	4				
CC[4]	-	5				
Grades[5]	-	A	A	A		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

interview. One factor that worked against achievement of the concept was a mathematical error made by the student while he was computing the percentage weight change in the system. Because of this error, the equation that the case study wrote for the reaction was at least qualitatively reasonable. The confusion of manganese with magnesium is a common problem that probably relates merely to the similarity of pronunciation.

I: What reaction were you talking about in class today?

CS: The reaction of hydrogen peroxide with magnesium dioxide.

I: What happened when they reacted?

CS: Released oxygen and produced H_2O plus magnesium oxide. After it was heated, H_2O evaporated, so that magnesium oxide was left.

I: You were given some data to analyze. What did you find out from the data?

CS: That it lost weight.

I: What range of loss in weight did you see?

CS: Ten percent.

I: What did you conclude from that?

CS: That the system did lose weight and we had to account for it. We concluded that the oxygen was released.

I: Can you write a chemical equation for the reaction?

CS: (wrote: $MnO_2 + H_2O_2 \rightarrow O_2 + H_2O + MnO$)

I: So, you said that part of the oxygen came from the MnO_2 and part of it came from the H_2O_2?

CS: Yeah.

I: How do you account for the loss in weight?

CS: A gas was released, and that accounted for some of the matter lost, and after it was heated, the water evaporated and that accounted for some more of the weight loss.

During the post-I discussion, the case study corrected his mathematical error, and he assimilated the information about the insignificance of the weight change in the system. He still expresses a perceived need to account for what weight loss there was in the system. This problem inhibited his accommodation of the overall concept. The case study came out of the class discussion with the knowledge that MnO_2 was a catalyst in the reaction and with a definition of a catalyst, but he has accommodated a mechanism for the catalytic action. The student no longer perceives MnO_2 as a reactant.

The beginning of the dialogue that follows relates to the class discussion of the reaction and the weight change data.

CS: We wrote down the reaction we had looked at earlier, looked at the weight change data, and concluded that the reaction was wrong. They we went through three or four other reactions trying to see how we could make it equal out and agree with the data we had. We finally concluded that the magnesium dioxide didn't change at all.

I: When we talked about it yesterday, you told me you had about a ten percent change in weight. Did you make a miscalculation?

CS: Yeah, I messed up bad.

I: Did you get the decimal point in the wrong place?

CS: Yeah.

I: Did you consider that one percent difference to be significant at the first of the discussion.

CS: Yeah.

I: Then you apparently rejected that idea. You said it was about when everyone else did. Why did you reject it?

CS: It didn't agree with the data...less than one percent is not going to affect it that much.

I: What if it had been two or three percent? At what point would you have started to wonder if the weight change was significant?

CS: I don't know.

I: Would you have been more reluctant to give up the weight percentage if it had been three percent, for example?

CS: Yeah, I think I would have.

I: When you were talking about the reaction, the class came up with $H_2O_2 + MnO_2 \rightarrow O_2 + MnO_2$, and you suggested water be added to that. What gave you the idea of water?

CS: The weight change, basically, because I was just trying to account for where the weight went, and I figured the water evaporated, plus you had to account for the hydrogen and the other oxygen some way or another.

I: So, you think that accounts for the weight change?

CS: Some of it, I guess. I'm not real sure.

I: What is the role of the MnO_2?

CS: Catalyst.

I: What is a catalyst?

CS: A substance that speeds up a chemical reaction without having a net change.

I: Net change in what?

CS: Weight.

I: What if we had twice as much MnO_2 as we did?

CS: It would have happened more readily and faster.

I: How does the MnO_2 increase the rate of a chemical reation?

CS: It has a pull on the O_2 in the H_2O_2; it has an attraction to the O_2, and it speeds it up.

I: I'm not quite sure what you mean there.

CS: I don't know either.

During the post-E discussion the interviewer engaged the case study in an extended interaction about the graphs of data from the E phase laboratory exercise (See Appendix 8A). During that part of the interview the case study essentially reiterated his statements about the rate effect from varying the amounts of catalyst. The E phase lecture and discussion had no apparent effect on the case study's mechanistic model for catalysis or on his definition.

I: What is a catalyst?

CS: A substance that speeds up a chemical reaction without undergoing a net change.

I: How do catalysts work; what do they do?

CS: Well, I'm not sure. It exerts a force on the substances that are reacting, and it just speeds them up.

The response of the case study to the content of the learning cycle seemed to follow the logical flow of assimilation in the G phase followed by accommodation in the I phase. The I phase served to correct an error as well as to provide language for the concept, but neither there nor in the E phase did the student show evidence of fully accommodating the insignificance of the weight change. It would seem reasonable that direct observation of the system, including a listing of physical properties of the MnO_2 before and after the reaction, would have enhanced such an accommodation.

Case Study 135. This student was described by his teacher as being slightly immature in his social dealings and having a relatively short attention span. He had considerable difficulty with the course content, and the difficulty he had compounded as the content became more abstract and more reliant on previously studied concepts. A profile of CS-135 is found in Table 8-8.

The experiment performed with Learning Cycle 10 was a data presentation form experiment, but this section was the control group. Since this section was the control group, all three phases of the learning cycle were performed, as

TABLE 8-8

CASE STUDY PROFILE

Student	135				Variable	Data Presentation
Sex	M				Group	Control
Class	25				LC 10	test scores (unadjusted)
Grade Level	11th					
Birthday	02-05-65				CAT 1	67 %
I.Q.	100				CAT 2	44 %
GEFT[1]	4	(Quartile 1)			CAT 3	44 %
VH[2]	3					
FR[3]	3	3				
CC[4]	4	4				
Grades[5]	B	B	B	B		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

written in the order of gathering data (G), invention (I), and expanding the idea (E). Four interviews were conducted with this case study during the course of the learning cycle. The first interview was held just prior to the beginning of the learning cycle (pre-LC), and the other three followed each phase of the learning cycle (post-G, post-I, and post-E, respectively).

The questioning in the interviews was designed to ascertain the case study's understanding of the central concept of the learning cycle at the various points in the learning cycle. The central concept of Learning Cycle 10 was that catalysts are substances which speed up a chemical reaction with no net change occurring in the catalyst.

When dialogue is recorded in the following survey of the interviews, the I represents the interviewer, and the CS represents the case study.

During the pre-LC interview the case study had no pre-conceptions about what a catalyst is. He appeared to understand some methods of speeding up chemical reactions, but the models that he had for them did not have a clear theoretical basis.

I: Can you tell me some ways to speed up a chemical reaction?

CS: Maybe add more of one substance to it, which you have already. Or heat it..., and that's about it.

I: What does heating it do?

CS: Speeds up the molecules and gets them going faster.

I: Have you ever heard the term catalyst?

CS: No, I think I've heard it, but I can't remember what it is.

I: You mentioned that heat would speed up the particles. Do you know how that would speed up a reaction?

CS: It would get the elements moving faster, I guess, or the molecules in the element, and that would make it go faster, instead of just waiting for it to happen by itself.

The case study had good memory of the procedural aspects of the laboratory activity in the post-G interview. The questioning revealed that the case study had not attempted to organize the laboratory data prior to the interview. There was no evidence that the case study was drawn toward the concept of catalysis as a result of the performance of the G phase. After the interviewer had asked several questions about the laboratory activity, the following dialogue occurred.

I: What do you think was left in the flask, when you got it back?

CS: Maybe manganese dioxide.

I: Why do you think it was manganese dioxide?

CS: Because of the oxygen left; there wasn't any oxygen left, so that just left manganese dioxide.

I: Could you write an equation for that reaction?

CS: (After writing hydrogen gas as a product and being questioned about his flammability test and the flammability test for hydrogen, the case study wrote: $MnO_2 + H_2O_2 \rightarrow O_2 + Mn + H_2O$).

I: What kind of percentage weight change did you have?

CS: Zero percent.

I: What does that mean?

CS: It means that the manganese stayed the same; that nothing was lost.

I: You started with manganese dioxide. In this equation you ended up with water, oxygen, and manganese. What kind of percentage weight change would that give you?...Is that going to be different from the percentage weight change you got?

CS: Should be, because you lost weight, I guess.

I: What weight have you lost?

CS: You lost the oxygen.

I: Does that represent what happened in your lab?

CS: No, because we didn't have a weight change.

As a result of the class discussion in the post-I interview the case study was able to write a correct equation for the reaction and to state a slightly incorrect definition for a catalyst. The case study was inconsistent in his explanation of the system, indicating that he still had not accommodated to the information he had assimilated. Furthermore, he was unable to apply the catalyst definition and the class discussion information to the laboratory system even in view of some explicit and leading questioning on the part of the interviewer.

I: Would you write the equation that you decided was correct in the class discussion?

CS: (wrote: $MnO_2 + 2H_2O_2 \rightarrow O_2 + M_nO_2 + 2H_2O$)

I: What purpose does the manganese dioxide serve? Is it a reactant?

CS: Yeah. That and hydrogen peroxide. Those are the reactants.

I: What are the products?

CS: Oxygen.

I: Is there anything else produced?

CS: Oxygen is the only thing produced.

I: What was left in the flask when you got it back from your teacher?

CS: There was a solid in the flask.

I: What was that solid?

CS: I guess it was manganese.

I: Just Manganese?

CS: Yes.

I: Just manganese by itself; not manganese dioxide?

CS: Yeah, manganese dioxide. MnO_2.

I: It was there when you started, and it was there when you finished. What purpose did it serve in that lab?

CS: I guess just to tell what happened to the rest of the substances like the oxygen and the hydrogen peroxide and the water.

I: How does it tell you what happened to them?

CS: Well, you could see that the oxygen left.

I: What happened to the water?

CS: It stayed there. It evaporated (later).

I: Will this reaction occur without the manganese dioxide?

CS: Yeah, it would take time, but it would happen eventually.

I: Why did you put manganese dioxide in the flask?

CS: I guess just to show maybe it might happen faster.

I: Did you talk about what a catalyst was in class?

CS: Yes, it's a substance you add to another substance that makes a chemical reaction speed up without undergoing a net charge; without gaining a net charge.

I: Have you worked with a catalyst?

CS: I don't think so.

I: Will this reaction occur without the catalyst?

CS: Yes, it would.

I: So, a catalyst wouldn't cause the reaction, it would just speed it up?

CS: Right.

I: But, you haven't worked with a catalyst?

CS: No, I don't think so.

The expansion laboratory and discussion provided the necessary situation for the case study to accommodate the role of MnO_2 in the system. As demonstrated during the post-E interview, his definition of catalyst still maintains the idea of "net charge" and adds the confusion of "net weight". This mistake could be a throwback to the atom discussions, in which ions were defined as atoms or groups of atoms with net charges. The case study's model for catalytic mechanism seems to relate to the temperature-rate effect idea that he had mentioned earlier.

I: What effect did varying the amount of MnO_2 have on the reaction? (This is referring to the E phase laboratory, see appendix 8A).

CS: The more of the MnO_2 you added to the H_2O_2, the more oxygen was produced.

I: What role did the MnO_2 play in this reaction?

CS: It was a catalyst.

I: What is a catalyst?

CS: A substance that speeds up a chemical reaction without undergoing a net charge...net weight.

I: Tell me what else you know about a catalyst.

CS: I guess that's all I know.

I: How does a catalyst speed up a reaction?

CS: It adds molecules, or something, that speeds it up, and it gets the other substance in there going faster and that makes the particles move quicker, I guess. It has more chance to react with each other.

I: Does the catalyst change at all?

CS: No.

The case study began the learning cycle with no previous knowledge about catalysts, and he concluded the learning cycle with a less than desirable definition for a catlyst and an almost nonsensical mechanism for the catalytic effect. He was not able to make an identification of a catalyst in the system until the last interview, which indicates that the I phase discussion was of little benefit to him. The case study seemed content to use terminology speculatively in attempting to answer the questions posed by the interviewer.

Summary. The value of small group discussions used as a post-G activity is illustrated by CS-502. This student, who was formal operational, used this small-group discussion to help him think about the data. From information from other students and from his own ingenuity he went through an invention stage, during the small-group discussion. The concept of catalysis, he derived from this, although still unrefined, was basically correct. The invention discussion, which followed this, refined the concept so that the exploration activity could firm-up this students knowledge of the concept. Because of this, the student did not seem to be penalized at all by the fact that this was a reading format learning cycle.

There is also some indication from CS-40 that at least some of our students may have prior knowledge of catalysis from earlier grade levels. Certainly, all of our students had heard the term catalysis used before, although many of them didn't know what the term refers to. There must be at least some of our students who have a latent knowledge for which our learning cycle is serving as a refresher.

Achievement Analysis

Two versions of the Cognitive Achievement Test (CAT) were developed for use with Learning Cycle 10. Sample examinations and grading criteria can be found in Appendix 8C. The first version, or A version, of the examination was used as a pre-test and the B version was used as both a post and retention test. There was no attempt to make the A and B tests equivalent to each other. The

TABLE 8-9: LC-10: RATES OF REACTION

ANOVA for CAT 1 (Pretest), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	2883	5.45	0.02	*
Class	4	633	1.20	0.32	
Class X Level	4	686	1.29	0.28	
Error	100	529			

Least Square Means

Level	CAT 1
concrete	25.4
formal	36.1

formal > concrete

Class	CAT 1
11	35.1
14	23.9
16	31.8
22	37.3
25	25.6

purpose of the pre-test was to confirm or deny that the classes were equivalent to each other and that the relative knowledge of the content of the learning cycle, and then six weeks later as a retention test.

As is summarized in Table 8-9, it can be seen that for the pre-test there is no main effect involving class differences. There is a main effect involving developmental level with formal students outscoring concrete students. It might also be noted, that the mean scores for the five classes average around 30%. These scores are low enough to warrant the assumption that there is little significant prior knowledge of this concept. The analysis of variance, for the post-test is summarized in Table 8-10 and shows a similar trend to the pre-test. Formal students score significantly higher than concrete students but there is no overall main effect between classes.

The retention test data summarized in Table 8-11 once again shows a main effect for developmental level with formal students outscoring concrete students, but no significant differences between classes.

Since there appeared to be noticeable, if non-significant, differences between classes on the post-test it was felt that there might be some difference in the amount of gain going from post-test to retention on this learning cycle. Table 8-12 summarizes the analysis of variance for the gain score and shows no significant differences either between developmental level or class.

In summary, the CAT analysis for this learning cycle shows no evidence of any "data presentation" form differences. Some of the observational data cited earlier indicates that a possible reason for this is a defect in the class activities themselves, which may have had a leveling effect on the results of the data presentation format.

TABLE 8-10: LC-10: RATES OF REACTION

ANOVA for CAT 2 (Post Test), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	1779	5.04	0.03	*
Class	4	607	1.72	0.15	
Class X Level	4	230	0.65	0.63	
Error	91	353			

Least Square Means

Level	CAT 2
concrete	65.6
formal	74.6

formal > concrete

Class	CAT 2
11	72.5
14	66.6
16	75.8
22	74.7
25	60.9

TABLE 8-11: LC-10: RATES OF REACTION

ANOVA for CAT 3 (Retention Test), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	5233	9.17	0.003	*
Class	4	263	0.46	0.76	
Class X Level	4	490	0.86	0.49	
Error	88	571			

Least Square Means

Level	CAT 3
concrete	59.3
formal	74.4

formal > concrete

Class	CAT 3
11	63.8
14	65.9
16	68.7
22	72.3
25	63.5

TABLE 8-12: LC-10: RATES OF REACTION

ANOVA for Gain Score (Post test → Retention), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P
Developmental Level	1	212	0.40	0.53
Class	4	537	1.00	0.41
Class X Level	4	812	1.51	0.21
Error	78	536		

Least Square Mean

Level	Gain
concrete	-3.4
formal	-0.03

Class	Gain
11	-8.5
14	0.5
16	-6.8
22	0.1
25	6.3

Attitude Analysis

Attitudes toward Learning Cycle 10 were derived from the BAR evaluations, using the two factors of contentment and comprehension, and from the spontaneous written comments which appeared on the reverse side of the BAR form. The tally forms for the BAR written comments for each class appear in the Appendix 8D.

The analysis of variance for the BAR contentment factor can be found in Table 8-13 and shows no significant difference between classes on this attitude factor. Similar results can be seen in Table 8-14 for the comprehension factor. Students appear to be equally content and equally confident of their comprehension no matter what format the data presentation took in this particular learning cycle.

The BAR written comments however show different patterns between classes. Section 14, which was one of the control groups, had a large number of overall comments, most of which were positive comments concerning the laboratory activity. Section 25, the other control group, had only a modest number of comments, the bulk of which also were positive comments concerning the laboratory. Section 11, which was the reading group, and 16, which was the demonstration group, both indicated a need for the laboratories, and a fair percentage of the comments were negative. These negative comments concern the readings in section 11 and concerned the questions in 16. Section 22, the discussion/lecture section, had a large number of comments indicating that they like laboratory work and missed it in this particular format. In summary, these written comments seem to indicate an appreciation for laboratory work and a disappointment when it was not a part of their learning cycle activites.

Conclusions

The overall results of this experiment, concerned with the form of the learning cycle, indicates little or no evidence that format differences were

TABLE 8-13: LC-10: RATES OF REACTION
ANOVA for BAR Contentment Factor

Source of Variation	DF	Mean Square	F	P
Class	4	39.0	1.50	0.21
Error	96	26.0		

Least Square Mean

Class	Contentment
11	26.5
14	29.4
16	26.9
22	28.5
25	25.7

TABLE 8-14: LC-10: RATES OF REACTION
ANOVA for BAR Comprehension Factor

Source of Variation	DF	Mean Square	F	P
Class	4	24.2	1.78	0.14
Error	95	13.6		

Least Square Mean

Class	Comprehension
11	32.5
14	34.2
16	32.2
22	31.9
25	30.7

important either from a learning or an attitude point of view. As far as the concept associated with this learning cycle is concerned, formal students seem much more able to learn the material than concrete operational students, at least initially. There didn't appear to be any differences overall on the retention of the concept over a period of time.

Two conclusions did come out of this learning cycle, which might account for a lack of class differences. First of all, the poor data that was obtained by the control groups in their laboratory activities might have affected the outcome of this form experiment. One lesson that might result from this is that the curriculum developer must assure himself that the data that comes out of the student experiment will illustrate the concept. It may be that the relatively poor showing of the control groups was a result of this defect in the curriculum activities rather than of the form that was being tested. A second indication is that small group discussions which are used to examine laboratory data are a valuable way of helping students understand the data from an experiment, no matter what the source of the data is. These small groups are especially effective if they have focussed questions as part of their assignment.

It may also be that because the expansion part of this experiment really diverged from the catalysis idea developed in the G and I phases of LC-10, that the learning associated with the first two phases of the learning cycle was diffused.

CHAPTER NINE

LC-12: HEAT LAWS

A SEQUENCE EXPERIMENT

Experimental Design

This learning cycle was designed to teach concepts associated with Heat Laws. As invented during the activities of LC-12, these concepts were stated as follows: (1) Chemical reactions can gain or lose energy in the form of heat, (these changes are termed endothermic and exothermic, respectively); (2) The amount of heat gained or released is directly proportional to the amount of reactants.

LC-12 was designed as a sequence experiment (See also LC-2). Table 9-1 summarizes the experimental plan for the manipulation of the sequence variable. This plan is similar to the plan for LC-2. Six chemistry section were involved. Each of the sections was assigned one of the six possible sequences of the three phases of the learning cycle; gathering the data (G), invention (I), and expansion (E). Three equivalent forms (A, B, and C) of the CATs were developed for LC-12. The same form (A) was used as the pre, post, and retention tests. The CATs were administered five times (CAT 1, 2, 3, 4, and 5); once as a pre-test and once after each cycle of the learning cycle and once as a retention test. The retention test was given two weeks after the post-test.

Because tests were administered after each phase of the learning cycle, it was possible to simulate necessity experiments. By using the post-phase, one test (CAT 2), for example, one could study the necessity of the other two phases. Similarly by using the CAT 3 scores, one could study the result of omitting only one phase. Several interactions between necessity and sequence are also possible (See Table 9-2 for examples).

Table 9-1
LC-12 Experimental Plan

pre-test Form A CAT 1

post-phase 1 Form B CAT 2

post-phase 2 Form C CAT 3

post-test Form A CAT 4

retention test form A CAT 5

Section	Phase 1	Phase 2	Phase 3
11	E	G	I
14	E	I	G
16	G	E	I
21*	G	I	E
22	I	G	E
25	I	E	G

*Control

Table 9-2
LC-12 Side Experiments

Section	Post Phase	Symbols	Type of Experiment
11	2	E only	Necessity
	3	E G	Necessity X Sequence
14	2	E only	Necessity
	3	E I	Necessity X Sequence
16	2	G only	Necessity
	3	G E	Necessity
21	2	G only	Necessity
	3	G I	Necessity
22	2	I only	Necessity
	3	I G	Necessity X Sequence
25	2	I only	Necessity
	3	I E	Necessity

Description of Classroom Activities

All three phases of the learning cycle were completed in each of the sections involved in this experiment. Because some phases of the learning cycle were not in their normal sequence in some section, some allowances had to be made in the content presentations. Class discussions, held during the invention (I) phase, are based on data that have been collected during the gathering data (g) phase. In situations where the I phase preceded the G phase in the sequence, the I phase became a lecture delivered by the teacher. (The invention lecture and class discussion notes are included in Appendix 9B.) These sequences were I, G, E; E, I G; and I, E, G. For the two experiments that began with the expansion (E) phase (E,I,G, and E,G,I), plus the sequence G, E, I, terse definitional statements were made about endothermic and exothermic processes, at the beginning of the E phase. Aside from these necessary modifications, the curriculum materials in LC-12 were presented as originally designed. Student handout materials used during LC-12 have been reproduced in Appendix 9A.

The specification of classroom activities by sequence and class days is summarized in Table 9-3. Appropriate appendix page numbers are given in parentheses.

Post-Experiment Discussion

At the end of learning cycle 12, the two participating instructors and the principal investigator gathered together to discuss observations that they had made during the learning cycle.

The first issue discussed was the difficulty of the concept. The general agreement was that this was a fairly difficult concept for the students and that they were especially confused by the distinction between temperature and heat. One of the staff members indicated that he thought that it might be necessary to rewrite the learning cycle for use the following year.

Section / Day	E,G,I 11	E,I,G 14	G,E,I 16	G,I,E (Control) 21	I,G,E 22	I,E,G 25
1	E Demonstration, questions (9A-7,9A-8)	E Demonstration, questions (9A-7,9A-8)	G Lab, Part I (9A-2 through 9A-5)	G Lab, Part I (9A-2 through 9A-5)	I Lecture (9B-2)	I Lecture (9B-2)
2	Reading A, Questions (9A-9 9A-11)	Reading A, questions (9A-9 through 9A-11)	G Lab, Part II, graph data	G Lab, Part II, graph data	G Lab, Part I, (9A-2 through 9A-5)	E Demonstration, questions (9A-7,9A-8)
3	E Lab, Reading b, questions (9A-12 through 9A-17)	E Lab, Reading b, questions (9A-12 through 9A-17)	E Demonstration questions (9A-7,9A-8)	Idea questions (9A-6)	G Lab, Part II, graph data	Reading a, questions (9A-9 through 9A-11)
4	G Lab, Part I (9A-2 through 9A-5)	I Lecture (9B-2)	Reading a, questions (9A-9 through 9A-11)	I Discussion (9B-3)	E Demonstration, questions, Reading 1 (9A-7 through 9A-11)	E Lab, Reading b, questions (9A-12 through 9A-17)
5	G Lab, Part II graph data	G Lab, Part I (9A-2 through 9A-5)	E Lab Reading b, questions (9A-12 through 9A-17)	E Demonstration questions (9A-7,9A-8)	Reading a, questions, E Lab (9A-9 through 9A-13)	G Lab Parts I & II (9A-2 through 9A-5)
6	I Discussion (9B-3)	G Lab, Part II, graph data	I Discussion (9B-3)	Reading a, questions (9A-9 through 9A-11)	Reading b, questions (9A-14 through 9A-17)	Complete G Lab & graph data
7	-------	------	------	E Lab, Reading b, questions	------	------

Another issue that was brought up concerned the students' apparent inability to gain information from reading. Since a portion of the content in the expansion of the learning cycle came from reading activities, it was felt that their inability to gain information from this reading may have made the expansion portion less effective. Luckily the expansion for Learning Cycle 12 was a fairly extensive one consisting of a demonstration, several readings and a laboratory activity. One of the instructors commented that reading difficulty left the instructor in a double bind. Students don't gain the information readily from the reading and so the discussion of the reading becomes more extensive and prescriptive than it would be otherwise. This, of course, just encourages the students to think that since a discussion is going to follow there's no sense in concentrating on the reading in the first place.

There was also a discussion concerning the difference between exothermic and endothermic processes and the explanation of them. According to one of the instructors there's the feeling that exothermic processes are easier to understand, and easier to explain theoretically than endothermic processes are.

There were also comments concerning the role of the expansion, and how it might serve as a mini-learning cycle, especially when it is utilized out of sequence. One of the instructors said, however, that she thought that the expansion exposed the student to too much even though it did serve as a mini-learning cycle. It might not serve as a mini-cycle as effectively as the regular GI phases sequence did. One of the other instructors said that he felt that when the lesson ended with a G phase it ended with no resolution. He said, "It felt like it ended with no resolution for me. Now, I didn't get the feeling from the kids. It didn't seem to bother them a bit. They seemed to be used to it, that is, having no resolution from many of the other classes in other educational experiences they've had." The point was made then, that part of the purpose of the experiment itself was to see whether the teacher's logic, that is the logic of the learning cycle, was also the student's logic. Whether the students were gaining as much from the out-of-sequence learning cycles as from the normal sequence. None of the observation data, however, seemed to give much evidence about a resolution to this problem.

Case Studies

Six students were chosen, one from each of the six experimental classes, to serve as case studies for Learning Cycle 12. Because of absences and in-school activities which were occurring during this time of the year, we lost the case study for class 25 and got incomplete information from several of the others.

The students chosen as case studies were chosen at random, but never-the-less are not considered to be necessarily representative of their classes. It was felt, however, that the case studies gave us insights to help us explain other observed and test data, gave us some insights into the learning cycle and its workings, and illustrated connections between the learning cycle and part of Piaget's functioning model.

Case Study 16. The teacher described this case study as an intelligent, hard-working student. He was very concerned about his studies and doing the right thing at all times. He was a foreign student from Iran. The first day he indicated that he had taken chemistry in his own country. During the interviews held with the case study he said that the first semester of our course was similar to what he had taken previously, but the second semester material was new to him. The teacher felt that the language was a problem for him particularly when he had to express his thoughts in writing. A profile of CS-16 is found in Table 9-4.

Learning Cycle 12 was a sequence experiment. A regular learning cycle consists of three phase: (1) a gathering data (G), (2) an invention (I),

TABLE 9-8

CASE STUDY PROFILE

Student	16			
Sex	M			
Class	11			
Grade Level	12th			
Birthday	04-02-65			
I.Q.	89			
GEFT[1]	-	(Quartile -)		
VH[2]	3			
FR[3]	5	6		
CC[4]	5	5		
Grades[5]	A	A	A	A

Variable Sequence

Group ECI

LC 12 test scores (unadjusted)

CAT 1	78 %
CAT 2	56 %
CAT 3	56 %
CAT 4	78 %
CAT 5	67 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

and (3) an expansion (E) phase. In a sequence experiment the order the student goes through the phases is altered. The case study was in the test group where the sequence was E, G, I. There were interviews held with the case study to determine his understanding of the concept of the learning cycle. These interviews were held before the learning cycle (pre-LC) and at various times during (post-E and post-G) and after the experiment (post-I). The central concept of learning cycle 12 was that reactions involve changes in the total energy of the reacting substances. The case study was asked the following questions in each of the interviews: (1) If a chemical reaction gives off heat, what is the source of that heat?, (2) Is it possible for a reaction to absorb heat? If so, explain, (3) How could you increase the amount of heat given off by a reaction?, (4) Are heat and temperature the same? Explain. The interviews with the case study were audiotaped. Each interview will be summarized, and then excerpts from the tapes will be used to illustrate points made in the summaries. I will designate the questions asked by the interviewer, and CS will stand for the responses given by the case study.

During the pre-LC interview the case study indicated that chemical reactions could give off heat. He had no idea of the course of the heat. When asked if heat and temperature are the same, he finally decided they were. He had a misconception concerning the definition of heat.

I: Do you recall an experiment that you put calcium metal in water? What happened?

CS: Bubbles, shape of calcium...

I: Do you remember anything about the temperature?

CS: It was getting hot.

I: I would like to talk about the heat. Have you noticed heat in other chemical changes?

CS: I think when substances are added they produce heat.

I: Where does the heat come from?

CS: ...I don't know. It usually get hot when it produces a gas.

I: With the calcium in water heat is produced. Is there an example where the opposite occurs--the test tube gets colder?

CS: Yes,...I suppose so.

I: If I had a chemical reaction like calcium in water that produces heat, can you think of any ways to increase the amount of heat?

CS: In the case with calcium and water, add more calcium.

I: Why does that cause more heat to be produced?

CS: There would be more reaction. The reaction would be bigger.

I: Is there a difference between heat and temperature?

CS: Temperature is how hot or how cold it is. It doesn't have to do with heat itself. The heat is just heating and getting more hotter.

I: What is heat?

CS: The moving of electrons.

I: The moving of what?

CS: I think the electrons move faster it would be hotter and temperature is the same thing--the measuring of the movement of electrons.

I: Oh, you are saying heat and temperature are the same thing or are they different ways of expressing the same thing?

CS: Well, you can measure the heat that would be temperature. You can measure the cold that would be the temperature...Heat is just heat.

During the post-E interview the case study demonstrated that he had been able to assimilate more information from the readings than other students have. He revealed several misconceptions such as the effects of increasing the amount of reactants and definitions of heat and temperature. He had assimilated but not accommodated the idea of the source of the heat in chemical reactions.

I: Since I have talked to you last, you have done a number of activities in class. Could you describe what you have been doing?

CS: We talked about the idea when we have a reaction whether it gives the heat or uses the heat.

I: You have done some reading, watched some demonstrations, and answered some questions. What readings have you done?

CS: We read two readings. The first reading gave us examples of how to find calories of heat released and molar heat. The other reading gave us examples of endothermic and exothermic reactions. When an egg is heated is endothermic, because it will absorb the heat. When we stop heating it, it will stop reacting. The burning of the paper is exothermic because even if we stop heating it will keep flaming and giving off heat. So it will have its own energy. It only needed a little to get started.

I: Let me ask you some questions about heat. Where does this heat come from?

CS: ...where the heat comes from?

I: Your teacher did some demonstrations with powdered zinc put in a copper (II) sulfate solution. What happened?

CS: It produced a gas and it was hot when you touched it.

I: Where did that heat come from?

CS: From the reaction itself--that is what I used to think--when something reacts the electrons move and hit each other. That's what produced heat.

I: There was another experiment--barium hydroxide and ammonium theocyanate powders were mixed together. What happened when she did that?

CS: It changed to a liquid and got cold.

I: How do you explain that it got cold?

CS: I think each substance has it own energy and so when it reacts with something else it has to use this energy. When it uses this energy, it gets cold because it would lose some of the energy.

I: What lost the energy?

CS: For being in the reaction that it could react with other substances that would produce energy.

I: Where did this energy come from or what is this energy?

CS. ...

I: If we have the zinc and copper (II) reaction which produced heat, how would we increase the amount of heat given off?

CS: By putting more of each substance.

I: So we could increase the amount of zinc for instance?

CS: Yes, and the amount of copper sulfate.

I: You took the copper sulfate and mixed it up with water. What if you increase the amount of water?

CS: I think it wouldn't be...that would not produce much heat. If it was more concentrated (more copper sulfate) it would produce more heat.

I: If I had 5 grams of zinc and mixed it with 5 grams of copper sulfate in 100 ml water, they would give off a certain amount of heat. If I used 200 ml of water, would it change the amount of heat given off?

CS: I think less heat would be given off.

I: How do you know it would give off less heat? How could you test that?

CS: We could use the therometer.

I: What's the difference between heat and temperature or are they the same thing?

CS: The temperature is the measure of the kinetic energy of the substance--how fast the electrons are moving. The heat is how much kinetic energy it has. I think it is the same.

I: So, it is just different ways of talking about the same thing?

CS: Yes. I never thought about it like that before.

I: Remember the two substances that you added and they got colder. What would happen if you increase the amount of those materials? Would it get colder, hotter, or stay about the same?

CS: I think it would reach just a certain temperature even if we add more. If you add more, it will last longer.

I: You say it would reach the same temperature but last longer.

CS: Maybe because there is more from each substance. If you use 1 mole it would be cold, if you use 1 mole of another substance it would be cold, and if you add them together it would be colder.

I: Somehow the heat is being removed from the system that is the reason it feels colder. Are you saying the amount of heat being removed is the same?

CS: Yes...I used to think that it would get colder, because we were using more. Now I think it would last longer.

During the post-G interview the case study corrected one of the misconceptions he stated in the post-E interview. The misconception dealt with what happens to the temperature of a reaction if more reactants are added. This evidence says that experience makes a difference in the student's understanding the concept. In the E phase the student had worked calorie problems, but in the G phase the student added various amounts of the substance to water and measured the temperature--had experience with the concept. The case study retained his misconception concerning the definitions of heat and temperature.

I: Why don't you describe the laboratory activity for me?

CS: First we found the temperature of the water, and then we put some different chemicals in it to see if it got hotter or colder. Some of them get hot and some of them get cold. Now I believe the more of a substance you put the hotter or colder it will be.

I: You didn't believe that before?

CS: I wasn't sure, but now I think I'm right.

I: Why do you believe that?

CS: Because when we did the lab today, we added $MgSO_4$ in the water. I used about 4 grams of $MgSO_4$ in 100 ml of water. The temperature change was about 5° C. It got hotter by 5°. Another friend of mine used 8 grams, and the temperature change was about 11° C.

I: So, you are basing this on direct experience you and this other person had?

CS: That's what I think.

I: A bunch of people collected this data. What did you do with the data? Did you graph it?

CS: Yes.

I: Have you talked about the graph in class?

CS: No.

I: What did your graph look like?

CS: I drew a line between all the dots. It had to be a straight line. A straight ratio between the more grams of $MgSO_4$ you put the hotter it will be.

I: Do you think you can predict what the temperature would be if I had 20 grams?

CS: I don't think so.

I: When $MgSO_4$ is put in water the temperature goes up, where does the heat come from?

CS: ...I don't know--some reaction to produce heat.

I: Where does the heat go to?

CS: It is gained by the water.

I: What is the difference between heat and temperature?

CS: They are the same.

I: Is heat the amount of temperature?

CS: Yes.

I: If I said how much heat did the water gain, what would you say?

CS: A temperature change of 5^{o}.

I: That's the amount of heat, then?

CS: Yes.

During the post-I interview the case study could not remember the laboratory activities in the G phase. It might be that going through the phases of the learning cycle out of sequence may have kept him from assimilating the laboratory activities. He had accommodated the idea that the substance is the source of heat. There was some disequilibration concerning absorption of heat without the temperature rising. He knew that heat and temperature were different. This series of interviews is evidence that the invention discussion is necessary to accommodate the material.

I: Since I have seen you last you had a discussion about the laboratory. Can you give me a description of the discussion?

CS: What was the laboratory over?

I: You dissolved a number of materials in water and measured the temperature changes. Next you and your classmates put varying amounts of one substance in water and measured the temperature changes. You may have had some questions. Did you?

CS: I don't remember.

I: What kind of things did you learn?

CS: The more substance you put the hotter it will be.

I: So, the amount of heat is dependent on the amount *of the substance you use.*

CS: Yeah.

I: You have changed your mind about that. When you first started this discussion, you thought it might stay hot a longer period of time. (The transcript of this discussion can be found in the post-E interview, page 9-10).

I: When you put the substance in water and it gives off heat, do you have an idea where the heat comes from?

CS: From the substance--it's potential energy.

I: Did you dissolve anything that got hotter?

CS: Magnesium sulfate.

I: Ok, let's take the magnesium sulfate. When you dissolved the magnesium sulfate, what got hotter?

CS: The temperature of the water.

I: Where did the heat come from?

CS: From the magnesium sulfate.

I: Where was the heat in the magnesium sulfate?

CS: I think it is potential energy.

I: Did the magnesium sulfate get hotter?

CS: No, it should get colder because it released heat and energy.

I: You put the magnesium sulfate in water. Are you saying the water got hotter and the magnesium sulfate got colder?

CS: I used to think the whole substance would get hot, but in the last two days I have learned the magnesium sulfate loses heat and the water gains it. So the magnesium sulfate should get colder. But the temperature we are measuring should be the temperature of them together.

I: It sounds like to me you are still a little uncertain about it. What about when a substance is dissolved and the temperature goes down?

CS: The ammonium nitrate gained heat from the water.

I: Where did the heat go?

CS: It was gained by the ammonium nitrate.

I: Does that mean the ammonium nitrate is hotter—like in the other case?

CS: Yeah.

I: We have been talking about heat and temperature. You indicated earlier that your ideas had changed. Can you tell me now what heat and temperature mean to you?

CS: Temperature is kinetic energy or the movement of electrons.

I: The movement of electrons?

CS: Yes. Temperature measures how fast the electrons are moving. Heat...I don't know.

I: Are heat and temperature connected in any way?

CS: Yeah, I think so. Heat will cause the electrons to move faster which will cause a rise in temperature.

I: Will 5 grams of magnesium sulfate release the same amount of heat that 10 grams will?

CS: No, it would release double the amount of heat.

I: So lets say I put 5 grams of water in 100 ml of water and it raises the temperature 10° C. Then I take 10 grams of magnesium sulfate in water. What do you think the temperature change will be?

CS: 20°.

I: Now, what if I put 5 grams of $MgSO_4$ in 100 ml and it raised the temperature 10° C. Then I put another 5 gram sample in 200 ml of water. What would happen to the temperature of the water?

CS: The temperature will rise 5° C.

I: So there isn't as much temperature change, is there as much heat?

CS: The heat released should be the same.

I: Why should it be the same?

CS: Because it has a certain amount of heat it can release.

I: Why didn't the temperature change the same amount?

CS: Because there was a different amount of water.

I: It seems to me you are indicating there is a difference between heat and temperature. Can you tell me what those differences are?

CS: It depends how much water. A certain amount of magnesium sulfate will release a certain amount of heat, so it depends how much water is used.

I: OK, if I put 5 grams of $MgSO_4$ in 100 ml and I put 10 grams $MgSO_4$ in 200 ml what would happen?

CS: The temperature change would be the same.

I: Is the amount of heat that's given off the same?

CS: No, the heat given off the second time is double.

I: Why?

CS: We used 5 grams the first time and 10 grams the second time, so 5 grams can give a certain amount of heat, and 10 grams can give double.

I: What if I put 5 grams of $MgSO_4$ in 100 ml water and I put 5 grams of another substance in 100 ml, will the temperature be the same?

CS: They will not be the same. I think that each substance has its own amount of heat it can give.

Case Study 23. The teacher described this case study as an involved, interested student who had set some expectations of herself. The case study would become involved in the classroom activities and finish the assignment but very often resisted thinking through the material. A profile of CS-23 is found in Table 9-5.

TABLE 9-5

CASE STUDY PROFILE

Student	23		Variable	Sequence
Sex	F		Group	EIG
Class	14		LC 12	test scores (unadjusted)
Grade Level	11th			
Birthday	05-10-65		CAT 1	67 %
I.Q.	120		CAT 2	56 %
GEFT[1]	12	(Quartile 3)	CAT 3	89 %
VH[2]	3		CAT 4	78 %
FR[3]	3	4	CAT 5	89 %
CC[4]	5	5		
Grades[5]	A	A	A	A

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.
2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.
4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).
5. Grades were given by the classroom teacher four times during the year.

Learning Cycle 12 was a sequence experiment. A regular learning cycle has three phases: (1) a gathering data (G) phase, (2) an invention (I) phase, and (3) an expansion (E) phase. The case study was in the test group where the order of the phases was EIG. The phases were conducted as in a regular learning cycle whenever possible. Since the I phase is normally a discussion of data collected during the laboratory activity in G, in this sequence (EIG) the invention phase was a teacher lecture over the same information as the discussion. There were four interviews scheduled with this case study: (1) a pre-learning cycle (pre-LC), (2) a post-expansion (post-E), (3) a post-invention (post-I), and (4) a post-gathering data (post-G). These interviews were held to determine the case study's understanding of the concept at the various times in the learning cycle. The central concept of Learning Cycle 12 was that reactions involve changes in the total energy of the reacting substances. The case study was asked the following questions in each of the interviews: (1) If a chemical reaction gives off heat, what is the source of that heat?, (2) Is it possible for a reaction to absorb heat? If so, explain, (3) How could you increase the amount of heat given off by a reaction?, (4) Are heat and temperature the same? Explain. The interviews with the case study was audiotaped. Each interview will be summarized, and then excerpts from the tapes will be used to illustrate points made in the summaries. I will designate the question asked by the interviewer and CS will stand for the responses given by the case study.

The pre-LC interview with this case study was not held.

During the post-E interview the case study had assimilated information from the E demonstration. She had formed some misconceptions concerning the reaction and source of the heat from the reaction. Her statement about heat and temperature indicated she really didn't know what they were.

I: A burning wood splint is an example of a chemical change. What evidenced of a chemical change are there?

CS: There's a temperature change. The wood changes to charcoal and can't change back.

I: You said the temperature changed, what do you mean by that?

CS: As it burns, it gets hotter.

I: So, heat was given off?

CS: Yes.

I: What is the source of the heat given off in that reaction?

CS: The flame burning the wood. I guess it's really the flame itself.

I: Where does the flame come from?

CS: The match.

I: Is it possible to have a chemical reaction that absorbs heat?

CS: Yeah.

I: If that is true, what would be happening to the heat going into the reaction?

CS: I guess it would be used to create the reaction and cool off the substances that are in the reaction itself.

I: Can you think of an example?

CS: Like we did yesterday with the $Ba(OH)_2$ that was hydrated and the NH_4SCN, when we put them together they cooled off.

I: Now tell me again why it cooled off?

CS: Instead of heating up as the reactants were put together they absorbed the heat as they reacted.

I: Where did that heat go?

CS: I'm not sure. I guess it went to change it from a solid into a liquid.

I: Let's go back to the reaction that gave off heat. How might you increase the amount of heat given off?

CS: If you increase the amount of one of the reactants--like if you have two wooden splints and one match--you would have twice as much heat.

I: What is the difference, if any, between heat and temperature?

CS: Temperature is the measure of heat or coldness. You can measure it in either terms. Heat is how hot something is. I guess it is essentially the same.

Before the post-I interview the case study had been through the E phase in which the demonstration and laboratory activity dealt with chemical systems which were endothermic and exothermic. Followed by this was the invention lecture which covered endothermic and exothermic dissolving processes. During the post-I interview the case study was trying to use dissolving terminology to explain the chemical systems in the E phase. In this process, also she had the definitions for endothermic and exothermic reversed. Her memory of the laboratory activities was good. She was conserving heat: that is, for heat to be absorbed by a system it would be absorbed from the environment. Another misconception the case study had was in the system she thought was exothermic, she associated gas production with heat release.

I: What have you been doing in class?

CS: She did a demonstration of ammonium dichromate. It was like a mini-volcano. Then in the lab we mixed calcium hydroxide and something and heated it. We wanted to see which was endothermic and which was exothermic.

I: Was there one of each:

CS: Yeah.

I: Which one was exothermic?

CS: The second one. The first one absorbed energy.

I: Explain to me how it absorbed energy.

CS: After we lit the match and started it, it went on by itself. The other one you had to keep applying the heat. When you took the heat away, it stopped reacting.

I: So, the one you put the match on and it reacted and kept reacting was endothermic, right?

CS: Yes.

I: What does endothermic mean to you?

CS: It means the solvent absorbs the energy.

I: Oh, what was the solvent when the orange, ammonium dichromate reacted?

CS: The solvent was the ammonium dichromate or... the match.

I: Was that a physical change when the ammonium dichromate burned?

CS: Chemical.

I: The heat that it absorbed while it was changing--where did it come from?

CS: It came from the air surrounding it and the table.

I: You said the system in the lab, $Ca(OH)_2$ and NH_4Cl, when heated gave off energy, right?

CS: Yes.

I: What evidence do you have that it gave off energy?

CS: A gas and water vapor produced. When you took the heat away, the gas wasn't produced anymore.

During the post-G interview the case study was still confused about exothermic and endothermic reactions. The readings in the E phase (Appendix 9A) gave examples of endothermic and exothermic systems. However, this had little, if any, effect on the case study's understanding. The reading 12b also discussed activation energy. She began to confuse endothermic and exothermic reactions with activation energy. As in the post-E interview she said that to increase the amount of heat, you would increase the amount of reactants. She knew temperature and heat are not the same, but she didn't know why.

I: In a previous interview you told me that a reaction can produce heat. An example of a reaction that produced heat is like burning a wooden splint. What is the source of the heat in a reaction like that?

CS: It comes from the kinetic energy that is produced when the two reactants form other products.

I: It is formed because of the kinetic energy, right?

CS: It is formed from the...it is formed from the reaction process itself as it is taking place...energy is given off because there is excell energy.

I: Do you know where that energy comes from?

CS: No, I don't.

I: Is it possible for a chemical reaction to absorb energy?

CS: Yes.

I: Where does that energy come from?

CS: From the surfaces surrounding it.

I: What is an example? Have you done any reactions that absorb heat?

CS: We did the little volcano, ammonium dichromate.

I: Did that reaction absorb heat?

CS: Yes.

I: Tell me the evidences that show you that it absorbed heat.

CS: After the match left the process it continued to react so it used energy that it had absorbed from other places to react.

I: What other places did it get energy?

CS: The ammonium dichromate itself, the table, and surfaces around it.

I: What is the name for that type of reaction?

CS: Endothermic.

I: Where does the energy that is being absorbed go?

CS: The reason it needs the extra energy is because it doesn't have enough energy of its own to react, so it pulls the extra energy from the places around it so it can react.

I: When it reacts what is the "fate" of that energy?

CS: You start out with less than you end up with, so you end up with more energy in the product, because you had to get more from outside sources.

I: In a reaction that gives off energy, how could you increase the amount of energy given off by the reaction?

CS: If you increase the reactants, you would increase the amount of energy.

I: Could you describe a relationship between the amount of energy produced and the reactants?

CS: If you measure a certain amount--like a teaspoon of each reactant--and that gives you a certain amount of energy. If you double the reactants--2 teaspoons of each--that would double the amount of energy.

I: How do you measure how much energy is given off?

CS: By temperature--measure the beginning temperature and measure the amount of increase for one teaspoon. Then measure the total increase for two teaspoons.

I: Does temperature change equal the energy change?

CS: Yes.

I: Are you saying temperature and energy are the same thing?

CS: No, at least in the reactions we have been working with the energy is usually heat. The way you measure heat is by temperature.

In summary, the sequence (E, I, G) seemed to have a negative effect on the case study. She could recite definitions for endothermic and exothermic reactions but had missed some essential observations to accommodate the definitions to the reactions. The case study understood that energy needed to be conserved but did not verbalize the idea of potential energy. In all, the sequence of the phases seemed to cause the case study to have several misconceptions of the concept of the heat changes involved in chemical reactions.

Case Study 48. The teacher described this case study as a very thoughtful, serious student. He was a senior in a class where most students are juniors. His plans are to attend college and he wanted to be prepared in his classwork. In class he was very cooperative and involved in the assignments. A profile of CS-48 is found in Table 9-6.

Learning Cycle 12 was a sequence experiment. A normal learning cycle has three phases: a gathering data (G) phase, an invention (I) phase, and an expansion (E) phase. In a sequence experiment the three phases of the learning cycle are conducted in a different order. The case study was in the test group whose sequence was GEI. There were four interviews scheduled with this case study: (1) a pre-learning cycle (pre-LC), (2) a post-gathering data (post-G), (3) a post-expansion (post-E), and (4) a post-invention (post-I) interview. These interviews were to determine the case study's understanding of the concept of the learning cycle 12 at the various stages. The central concept of learning cycle 12 was that reactions involve changes in the total energy of the reacting substances. The interviews were audiotaped. Each interview will be summarized and excerpts from the tapes will be given to demonstrate the points made in the summary. I will designate comments or questions by the interviewer, and CS will stand for the responses by the case study.

During the pre-LC interview the case study demonstrated he had an idea

TABLE 9-6

CASE STUDY PROFILE

Student	48			Variable	Sequence
Sex	M			Group	GEI
Class	16			LC 12	test scores (unadjusted)
Grade Level	12th				
Birthday	11-10-64			CAT 1	67 %
I.Q.	123			CAT 2	89 %
GEFT[1]	10	(Quartile 2)		CAT 3	99 %
VH[2]	5			CAT 4	78 %
FR[3]	6	6		CAT 5	99 %
CC[4]	4	5			
Grades[5]	A	A	A	A	

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

about substances storing heat. He was confused whether heat and temperature are the same thing.

I: In the system, calcium in water, what were the evidences of chemical change?

CS: Hydrogen was given off, and calcium oxide was formed. It is insoluble in water, so it formed on the bottom as a precipitate. There might have been heat produced.

I: In fact, the beaker got quite hot. What would have been the source of the heat?

CS: The oxygen and hydrogen molecules in the water split apart. There was energy there that was released from the bonds. Maybe that would produce heat.

I: You said energy in the bonds would produce heat. Would you explain your concept to me?

CS: Your oxygen and two hydrogen are held together by bonds or magnetic forces or something. When that is broken, the energy that is keeping the hydrogen and oxygen together could be heat and spread out into the water.

I: Is it possible for a chemical reaction to absorb heat?

CS: I guess so. When things are combined...some things have to be heated to get them to combine.

I: If heat was absorbed, how could you account for this?

CS: The bonds...energy is derived from the heat because heat is energy (kind of). Heat holds things together.

I: How could you increase the amount of heat given off by a reaction?

CS: You could speed up the reaction--get more of the stuff reacting--it would give off more heat. Add a catalyst.

I: Is there any other way you could do it besides adding a catalyst?

CS: If you had substance A and substance B combining, and you put more of substance B in that would mean as A was moving around it would more easily find B and combine. You would have B left over in the end but they would still combine quicker.

I: How would you measure the amount of heat given off?

CS: Use a thermometer.

I: How would that do it?

CS: The more heat there is the higher up the thermometer would read because the more energy is given off the more heat is put into the liquid. The more heat there is the higher the heat to the water ratio--more heat in every ml of water.

I: Is there a difference between temperature and heat?

CS: I'm really not sure. Temperature is the average kinetic energy of the molecules. I know that. Heat, I'm not sure about. I would imagine they are the same thing. You can't have one without the other.

The other interviews with this case study were not held.

Case Study 85. This student was described by her teacher as being a diligent worker. She seldom initiated discussion, but she was always attentive and willing to contribute, when drawn into a discussion. Her interaction with other students in laboratory and small group settings was much more pronounced and frequent. A profile of CS-85 is found in Table 9-7.

The experiment for Learning Cycle 12 was a sequencing experiment. The section, of which this case study was a member, was the control group, and they were taken through the learning cycle in the normal order of gathering data (G), invention (I), and expanding the idea (E). Four interviews were conducted with this case study: pre-LC was held just prior to the beginning of the learning cycle; post-G, post-I, and post-E were conducted following each of the respective

TABLE 9-7

CASE STUDY PROFILE

Student 85

Sex F

Class 21

Grade Level 11th

Birthday 06-29-65

I.Q. 107

GEFT[1] 16 (Quartile 4)

VH[2] 5

FR[3] 5 6

CC[4] 5 6

Grades[5] A A A A

Variable Sequence

Group GIE Control

LC 12 test scores (unadjusted)

CAT 1 78 %

CAT 2 78 %

CAT 3 89 %

CAT 4 78 %

CAT 5 89 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

phases of the learning cycle.

The content of this learning cycle dealt with energy changes in physical interactions (dissolving processes) and chemical reactions. The case study was questioned to ascertain her understanding of these ideas and to prove her theoretical models for these ideas. In the dialogue that follows, I stands for interviewer and CS stands for case study.

When questioned during the pre-LC interview, the case study stated a model for heat production in a chemical reaction that hypothesized the source of heat to be friction between reacting molecules. She had an intuitive grasp of the direct relationship of heat production and amounts of reactants. The case study was not able to distinguish between heat and temperature, but she did not directly say that they were the same thing.

I: What evidences do you use to tell if a chemical change has occurred?

CS: Change in the substance, like in the shape and size and color. If there is a gas produced or a heat change.

I: Can you describe what you mean by heat change?

CS: When you feel the test tube and it's hot.

I: Where does the heat come from that heats up the test tube?

CS: Reacting molecules produce heat; like latent heat that comes out in the reaction or friction between molecules or something.

I: How might I go about increasing the amount of heat that is given off by a chemical reaction?

CS: You can put in more reactants. They would react longer or more strongly; or you could use a catalyst.

I: How would a catalyst work?

CS: It sould speed up the reaction. I don't know if it would produce more heat or not.

I: What about increasing the amount of reactants?

CS: There are more reactants, and there will be more heat produced.

I: Why would you think that would be the case?

CS: Whatever makes the heat, there would be more of it; more friction.

I: Could you design an experiment to tell the amount of heat given off by a chemical reaction?

CS: You could measure the temperature of each of the reactants, then put them together and measure that temperature.

I: Then what would you do to figure out how much heat was associated with it?

CS: Use a thermometer.

I: Are heat and temperature the same thing?

CS: Heat is a form of temperature... temperature is the measure of how much the molecules are moving around; heat means the molecules move around more; cold means that they move less.

During the post-G interview the case study's model of heat production in an exothermic process was considerably more refined in this interview than in the pre-LC interview. Since the G phase involved a laboratory activity with no theoretical discussion, it can be assumed that the questioning in the pre-LC interview cued some further thought on the question by the case study. The case study still remained unable to differentiate between heat and temperature, although she did not state that they were the same.

I: Let's take, for example, one of the systems where the temperature went up. What did you measure the temperature of?

CS: The solution; the water and the substance.

I: Where did the heat come from?

CS: Maybe when it dissolved there was some heat given up by the substance.

I: What are your other choices for the source of heat?

CS: When the molecules move around more, it could produce heat. The ions are moving around more in solution. I don't know how the heat would decrease in the others, though.

I: Can you tell me about what heat is and what temperature is?

CS: Not really. Like a comparison; something can be more hot than another thing, so their temperature would differ; heat is relative to other things.

I: What is heat relative to?

CS: The heat of one substance is relative to the heat of another.

I: Can you give me an example of what you mean to make it clearer?

CS: When you boil water, you can say that is hot. When you go outside, you can say that's hot too, but one of them is more hot.

The class discussion was useful to the case study in that it provided some language for her to attach to the heat transfer situations. It may also have aided in the continued improvement of her model for heat transfer within chemical systems. There is evidence from the post-I interview that the case study had accommodated to the distinction between heat and temperature.

I: Say you had used 100 ml of water in dissolving a certain amount of anhydrous magnesium sulfate. How would 200 ml affect the experiment?

CS: If you used $MgSO_4$ and it got hotter in 100 ml, it wouldn't get as warm if you used 200 ml.

I: Why not?

CS: Because there is more cool water. It's kinda like the heat is diluted.

I: What would happen to the temperature change?

CS: It would go down.

I: Does that mean that less heat is given off when you have more water?

CS: No, it just means that the coolness of the water takes up the heat more.

I: Where does the heat come from?

CS: From the substance. When it's dissolved in water, the heat is released; the potential heat of the substance is given off.

I: Where does that heat go?

CS: It goes into the whole solution.

I: Do you know any examples where the temperature of the water gets cooler rather than hotter?

CS: Hydrous $MgSO_4$; that got cooler.

I: Can you give me an explanation of how that might work?

CS: When the substance dissolved in the water, it takes up energy from the water, and the whole thing gets cooler. But I don't understand why one substance gets hotter and another substance gets cooler.

I: Is there a difference between heat and energy?

CS: Heat is energy and temperature is the measure of energy.

I: If I were to ask you to make a distinction between a substance giving off heat in water and a substance causing the temperature to go up, what would you say?

CS: If it gave off heat, that means it was giving off some kind of energy and if you take the temperature you are measuring how much energy it gave off.

In the post-E interview the case study used the term "potential energy" to describe the energy transferred in reactions. There was some confusion in the explanation of the energy change in an endothermic system, although the student worked out some of the difficulty during the discussion. The case study inferred an understanding of the idea that total energy is the sum of kinetic energy and potential energy.

I: Consider the exothermic reaction of zinc with copper (II) sulfate. Where did the heat come from and where did it go?

CS: It came when the two substances reacted, and it was from the potential energy of both of them. When they reacted, it was released, and it increased the total energy of the system.

I: You say the energy comes from the reaction. Do you have an idea of a mechanism to explain the release of heat?

CS: I guess the ions, when they split apart--like the copper and sulfate ions--release some heat and then when zinc reacts with sulfate and combines, it releases heat, maybe.

I: What is the difference between a reaction that releases heat and one that gains heat?

CS: I'm not sure.

I: Let's take the endothermic reaction. How does this one work?

CS: Two solids were mixed together, and somehow they absorb energy and then it gets cooler.

I: What is the source of the energy?

CS: I guess the potential energy of the reactants.

I: What happens to that potential energy?

CS: Maybe, in this reaction, the reactants gain more potential energy and that's how they absorb the heat.

I: Why is it possible for them to gain more potential energy?

CS: Because they are endothermic.

I: Where does this energy come from that it absorbs?

CS: From the kinetic energy, I guess, of the two substances.

I: What is the difference between heat and temperature?

CS: Heat is the kinetic energy of a substance and temperature measures the amount of kinetic energy.

I: Can you explain that further?

CS: The kinetic energy of a solid is just there, but then if you measure the temperature, you are giving the amount of kinetic energy it has--average--in degrees.

I: How does potential energy fit into this?

CS: Potential energy would be the energy that would be released during a reaction. You can't really measure its temperature because you don't know what it is.

The case study represented an almost ideal situation where assimilation and accommodation are related to successive phases of the learning cycle. The case study's model of heat transfer in chemical systems became successively more refined, with each phase of the learning cycle. Any deficiencies in the students final structures were probably more a function of the content covered in the learning cycle than of the student's success at accommodating to the content.

Case Study 104. This case study was described as being reserved in her interaction during class discussions. She did not always grasp the concepts being studied, but she consistently worked toward that goal. Her reserve seemed to stem from a desire to avoid embarrassment for giving an incorrect response. A profile of CS-104 is found in Table 9-8.

The experiment for Learning Cycle 12 was a sequencing experiment. The section, of which this case study was a member, experienced the content in the sequence invention (I), gathering data (G), and expanding the idea (E). Four interviews were scheduled with this case study, but, owing to subsequent

TABLE 9-8

CASE STUDY PROFILE

Student	104				Variable	Sequence
Sex	F				Group	IGE
Class	22				LC 12	test scores (unadjusted)
Grade Level	12th					
Birthday	01-08-64				CAT 1	22 %
I.Q.	110				CAT 2	56 %
GEFT[1]	14	(Quartile 3)			CAT 3	67 %
VH[2]	3				CAT 4	78 %
FR[3]	4	4			CAT 5	67 %
CC[4]	4	6				
Grades[5]	A	B	C	C		

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

scheduling conflicts, only two interviews were held. They were the pre-LC interview (held just prior to the beginning of the learning cycle) and the post-I interview (held following the invention lecture).

The content of this learning cycle dealt with energy changes in physical interactions (dissolving processes) and chemical reactions. The case study was questioned to ascertain her understanding of these ideas and to prove her theoretical models for these ideas.

During the pre-LC interview the case study suggested a "friction" model for energy production in a chemical change (i.e., molecules rubbing together increase their kinetic energy). She demonstrated a qualitative grasp of the effect in heat production of varying amounts of reactants, but she had the misconception that heat and temperature are the same thing.

I: What are some evidences of chemical change?

CS: Color change, if there is a precipitate, if it's conductive, litmus paper change, heat produced.

I: When a system reacts and produces heat, what is the source of the heat?

CS: The substances reacting together; the molecules combine. The heat caused by molecules rubbing together and producing kinetic energy.

I: Can you think of a way to increase the amount of heat that's given off?

CS: Maybe if you added more of one of the substances.

I: How could we measure the amount of heat that's given off?

CS: You could use a thermometer and measure the temperature.

I: Are heat and temperature the same thing?

CS: Yeah, because temperature is the average of the kinetic energy, and I guess that's the heat.

After the invention lecture (post-I interview) the case study had assimilated operational definitions for endothermic and exothermic solution processes. These definitions were stated in terms of the temperature change in the respective solutions. The case study still equated heat and temperature, as indicated by the following dialogue.

I: Are heat and temperature the same thing?

CS: I think they are.

I: What is heat?

CS: It's the kinetic energy from whatever substance it is. It produces a kinetic energy and that's heat.

I: How do you measure that heat?

CS: By a thermometer.

The invention lecture (See Appendix 9B) had nothing in it that could have changed the case study's conception of the equivalence of heat and temperature. The lecture provided language for concepts that the case study had already grasped intuitively, but it did not provide the student with a reasonable model for energy transfer.

Summary. Case study 16, which came from class 11, gave some evidence that there was a lot of confusion if a large number of activities precede the invention discussion as was the case with the EGI sequence.

Past learning cycles indicated that the expansion phase of the learning cycle might act as a mini-learning cycle. With case study 23, however, the evidence indicated that the E phase acted not so much like a mini-learning cycle as much as a substitute for the G phase. Evidence for this is in that it seemed to result in the student assimilating information from the activity but did not result in any accommodating of the concept being taught. For this student, there was a partial accommodation but some confusion after the I phase. He did try to use of the I terminology, although incorrectly, on the E data, but this was not resolved by the post-test.

Case study 85 came from class 21, the control group. This student presents the best clear demonstration of an assimilation to accommodation model. The case study's model for the concept becomes progressively more refined with each phase of the learning cycle. At least for this student, normal sequence of phases seems to be effective.

Achievement Analysis (Sequence)

Three forms of the CAT test were utilized to assess achievement in learning cycle 12. Copies of the forms and the grading criteria used to grade the forms can be found in Appendix 9C. These three forms will be considered equivalent as a result of the cross-validation study which was described in Chapter 2. One of the forms scores were adjusted as a result of this cross-validation study and the results described in this chapter are based on these adjusted scores.

The various versions of the CAT analysis was given as a pre-test after each of the phases of the learning cycle and as a retention test given three weeks later. Because of end of the semester activities, we were forced to use a three week delay rather than normal six week delay used in retention tests on other learning cycles.

The six different classes each had one of the six possible sequences with the three phases of the learning cycle. Table 9-9 summarizes the analysis of variance for all of the five CAT tests by developmental level and class. As can be seen from this analysis of all five CAT tests from pre-test to retention test there were differences between the concrete and formal operational students, with the formal students scoring higher than the concrete students. The main effect of differences between classes show that there is no significant difference during the pre-test. Furthermore, there is no significant difference during the

TABLE 9-9: LC-12: HEAT LAWS

ANOVA for All CATs (CAT 1 ⟶ CAT 5), Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P
CAT 1 (Pretest)				
Developmental Level	1	8627	23.16	0.0001 *
Class	5	340	0.91	0.48
Class X Level	5	525	1.41	0.22
Error	115	372		
CAT 2 (Post Phase 1)				
Developmental Level	1	6813	18.95	0.0001 *
Class	5	548	1.52	0.19
Class X Level	5	124	0.35	0.88
Error	112	360		
CAT 3 (Post Phase 2)				
Developmental Level	1	2304	7.78	0.006 *
Class	5	696	2.35	0.05 *
Class X Level	5	205	0.69	0.63
Error	105	296		
CAT 4 (Post test)				
Developmental Level	1	5352	18.86	0.0001 *
Class	5	383	1.35	0.25
Class X Level	5	207	0.73	0.60
Error	116	284		
CAT 5 (Retention)				
Developmental Level	1	3618	14.47	0.0002 *
Class	5	620	2.48	0.04 *
Class X Level	5	122	0.49	0.79
Error	118	250		

TABLE 9-10: LC-12: HEAT LAWS

ANOVA for All CATs (CAT 1 ⟶ CAT 5), Developmental Level vs. Class

Mean Comparisons by Newman Keuls (α = .10)

	Level Means			Class Means						
Test	concrete	formal		11	14	16	21	22	25	
CAT 1	48.5	65.8	f > c	57.3	53.5	59.2	63.7	51.7	57.4	
CAT 2	54.3	69.5	f > c	62.0	51.9	65.8	66.3	60.0	65.4	
CAT 3	56.4	65.6	f > c	50.9	64.7	5[illegible].6	66.3	65.1	62.4	14,21,22>11
CAT 4	60.8	74.3	f > c	66.4	68.0	62.[illegible]	74.6	68.9	65.5	
CAT 5	63.9	74.8	f > c	72.4	76.2	62.5	[illegible].1	64.7	66.2	14 > 16

post phase 1 test. Studying the class means found in Table 9-10, it cannot be shown that classes 22 and 25, which had the invention discussion, faired any better than any of the other classes in their understanding of the concepts of the learning cycle.

Post-phase 2, however, does show main effect differences between classes. This effect is summarized in Table 9-11 as classes 14, 21, and 22, having signigicantly higher scores than section 11. The other two classes, 16 and 25, fall someplace in between. All three of these significantly higher sections had a combination of the invention discussion and some laboratory activity. In the case of 21 and 22 both of them had gathering-the-data and invention discussions although in a different order. Section 14 had an expansion followed by the invention. Both section 11, which was significantly lower than these three, and section 16, which fell someplace in between them, had not as yet had an invention discussion. Section 25 had an invention discussion but it was followed by an expansion which was very long and complicated, which might have negatively influenced students learning.

The post-test shows no significant difference according to class. Studying the means, however, shows that sections 21, 22, and 14 still are the top three rated classes as in CAT 3.

The retention test once again shows a class difference with section 14 being significantly greater than section 16. In comparing these two sections 14, had an EIG sequence, and section 16 had a GEI sequence.

It has been argued previously that the expansion activities themselves might change in character depending upon their place in a sequence. The argument goes something like this. Since the expansion phase often consists of laboratory activities, which are similar to the gathering-the-data activities, the two phases might be interchangeable. Therefore, an expansion activity that begins the learning cycle would take the form of a gathering-the-data phase. Using this argument, the GIE sequence might be considered to be intellectually equivalent to the EIG sequence. In summary then, it might be that the position of the invention phase is the critical factor in the learning cycle sequence. In order to test out this idea, the classes were combined into three groups. Sections 14 and 21 were combined, consisting of the EIG and GIE sequences. Sections 11 and 16 were combined. In these combinations the invention discussion became the third phase of the learning cycle (EGI and GEI). Finally sections 22 and 25 were combined. These consist of phases of IGE and IEG where the invention is the initial phase of the learning cycle.

Tables 9-11 and 9-12 summarizes the analysis of variance for the combined classes. Although the pre-test shows no significant differences between classes there is an interaction of class and developmental level which needs to be discussed. Comparison of the means for this discussion can be found in Table 9-13. The interaction effect concerns the formal operational groups of classes 11-16 outscoring the formal operational students of classes 25-22. The rest of this interaction effect takes place because formal students scored better than concrete students in all three classes. In fact, formal students scored better than concrete students on all five CAT analyses. No significant differences between classes can be found at CAT 2, which is the post phase 1.

However, class differences can be seen for the post phase 2, the post phase 3, and the retention scores. As can be seen from Table 9-12, comparing class combination means shows that class combinations 14-21, which has the invention in the second phase, and classes 25-22, which has the invention as the first phase, scored significantly greater than classes 11-16, which had the invention as the third phase. Since this particular CAT was given after the second phase, section 11-16 did not as yet have the invention discussion and

TABLE 9-11: LC-12: HEAT LAWS
ANOVA for All CATs (CAT 1 ⟶ CAT 5), Developmental Level vs. Combined Classes

Source of Variation	DF	Mean Square	F	P
CAT 1 (Pretest)				
Developmental Level	1	8725	23.39	0.0001 *
Class	2	86	0.23	0.80
Class X Level	2	954	2.56	0.08 *
Error	121	373		
CAT 2 (Post Phase 1)				
Developmental Level	1	7298	20.22	0.0001 *
Class	2	211	0.59	0.56
Class X Level	2	433	1.34	0.27
Error	118	361		
CAT 3 (Post Phase 2)				
Developmental Level	1	2826	9.69	0.002 *
Class	2	1708	5.85	0.004 *
Class X Level	2	137	0.47	0.63
Error	111	292		
CAT 4 (Post Test)				
Developmental Level	1	5973	20.11	0.0001 *
Class	2	695	2.45	0.09 *
Class X Level	2	63	0.22	0.80
Error	122	283		
CAT 5 (Retention)				
Developmental Level	1	4018	16.10	0.0001 *
Class	2	1086	4.35	0.01 *
Class X Level	2	122	0.49	0.62
Error	124	250		

TABLE 9-12: LC-12: HEAT LAWS
ANOVA for All CATs (CAT 1 → CAT 5)
Developmental Level vs. Combined Classes
Mean Comparisons by Newman Keuls (α = .10)

	Level Means			Class Means			
Test	Concrete	Formal		11-16	14-21	25-22	
CAT 1	49.4	66.3	f > c	58.3	59.1	56.2	
CAT 2	54.3	69.9	f > c	64.1	59.6	62.6	
CAT 3	56.0	66.0	f > c	53.7	65.8	63.5	25-22, 14-21 > 11-16
CAT 4	60.4	74.3	f > c	63.5	71.9	66.6	
CAT 5	63.6	74.9	f > c	67.2	75.3	65.3	

TABLE 9-13: LC-12: HEAT LAWS
ANOVA for CAT 1, Developmental Level vs. Combined Class
Interaction of Developmental Level X Combined Class

	Level		
Class	Concrete	Formal	
11-16	44.4	72.1	
14-21	53.1	65.0	11-16 f > 25-22 f
25-22	50.6	61.8	

the students had to take the test without the benefit of the invention discussion.

Both the CAT 4, which was the post-test, and the CAT 5, which was the retention test, also showed class differences. The Newman-Keuls, which is a fairly conservative test, was unable to identify what specific differences were the result. An interpretation of this data would indicate that the variance was spread equally between the three combination classes. In both cases, the sequence represented by classes 14-21 had the highest mean scores. This combination represented the invention phase being in the second phase of the learning cycle.

An interpretation of the sequence analysis seems to indicate that sequences where the invention phase is sandwiched between activities is preferable to other phases where the invention either comes last or is the initial phase of the learning cycle.

Trend Analysis. Using a repeated measure design an analysis of variance was done across CAT examinations going from CAT 1 to CAT 5, in each of the class combinations. Table 9-14 summarizes this trend analysis for combined classes 11 and 16. These combined classes represent the invention discussion coming last in the sequence of phases of the learning cycle. As one can see from this analysis there is a developmental level effect with formal students outscoring concrete students, an overall test effect, and an interaction between test and level. In examining the means of these scores it can be shown that CAT 3, which represents the scores before the invention discussion took place, has lower scores than any of the other CATs. This is true overall, it's true for formal operational students, and with one exception is also true for concrete students. This sequence represents a deterioration of the score as the students become more confused as they go through a number of activities without the benefit of the invention discussion which is saved until last. There is no overall gain in

TABLE 9-14: LC-12: HEAT LAWS

Trend Analysis, CAT 1 → CAT 5, Class 11-16

Source of Variance	DF	Mean Square	F	P	
Developmental Level	1	13293	15.14	0.0005	*
Error	33	878			
Test	4	548	3.54	0.009	*
Test X Level	4	569	3.68	0.007	*
Error	132	155			

Least Square Means

CAT	Concrete	Formal	Overall
1	43.8	75.2	60.0
2	55.8	70.3	63.2
3	48.8	60.8	54.9
4	53.6	70.6	62.3
5	58.9	71.2	65.2

CATs 5, 2, 4 concrete > 1 concrete

CAT 5 concrete > 3 concrete

CATs 1, 5, 4, 3 formal > 3 formal

CATs 5, 4, 3, 2 overall > 3 overall

formal > concrete

score from pre to post tests, and no obvious build-up of knowledge over the sequence.

Table 9-15 summarizes the trend analysis for classes 14 and 21. These combined classes represent the control versions where the invention discussion is sandwiched between the gathering the data and the expansion phases of the learning cycle. As one can see there is an overall main effect for developmental level and for tests. In studying means it can be shown that there is an overall pre to post test gain but in fact there is also a gain of CAT 2 over 1, CAT 3 over 1, CAT 4 over 1, 2, and 3, and CAT 5 over 1, 2, and 3. To summarize this information it appears that the CAT examinations fall into three major groups. The groups represented by the pre-test; a group represented by CAT 2 and 3, which is post phase 1 and phase 2; and then finally a CAT 4 and 5, which represent the post test and retention tests. This indicates a sequence effect. There appears to be a gradual build-up of information over a period of time as the sequence goes from one phase to another.

Table 9-16 represents the trend analysis going from CAT 1 to CAT 5 for class combination 22 and 25. This combination includes those sequences where the invention discussion comes first. As we can see there is an overall effect involving the test. The CAT examination mean scores show significant differences of all the CATs, 2, 3, 4, and 5, over the pre-test. This means that this trend falls into two major categories, the pre-test and all of the other tests. Since the CAT 2 represents the invention discussion, this means that all of the gain in score was benefited by the invention discussion but no further gains in scores, at least from a significant point of view, can be seen thereafter.

The overall effect of the trend analysis seems to support the idea of an ideal sequence which consists of the invention phase coming after some introductory activities and before some sum-up activities.

TABLE 9-15: LC-12: HEAT LAWS

Trend Analysis, CAT 1 ⟶ CAT 5, Class 14-21

Source of Variation	DF	Mean Square	F	P
Developmental Level	1	10350	11.15	0.003 *
Error	24	928		
Test	4	1216	9.40	0.0001 *
Test X Level	4	244	1.88	0.12
Error	96	129		

Least Square Means

CAT	Scores	
1	59.6	
2	64.9	2 > 1
3	68.0	3 > 1
4	73.6	4 > 1, 2, 3
5	77.1	5 > 1, 2, 3

TABLE 9-16: LC-12: HEAT LAWS

Trend Analysis, CAT 1 → CAT 5, Class 22-25

Source of Variation	DF	Mean Square	F	P	
Developmental Level	1	2361	2.19	0.15	
Error	24	1078			
Test	4	516	2.97	0.02	*
Test X Level	4	102	0.58	0.67	
Error	96	174			

Least Square Means

CAT	Scores	
1	54.3	
2	62.7	2 > 1
3	62.9	3 > 1
4	65.5	4 > 1
5	64.7	5 > 1

Achievement Analysis (Necessity)

From Tables 9-9 and 9-11 it can be seen that no single phase of the learning cycle stands out as better than any of the others when used alone. Studying the CAT 2 data from both of these tables shows that after phase 1 there is no significant differences between the groups. Studying Table 9-9, the CAT 3 table does show significant differences favoring those sequences which include I either in combination with G or E phases. This is further supported by the Table 9-11 CAT 3 data, which again shows a superiority of those sequences which after the second phase have an invention discussion in combination with G or E. The indication from this information is that the I phase is a necessary part of the learning cycle when it is found in combination with G or E phases.

Table 9-17 summarizes the analysis of variance for the post-G test, no matter when G was done. Classes 14 and 25 then have completed learning cycles. Classes 11 and 22 have two phases of the learning cycle and classes 16 and 21 have only one phase of the learning cycle. The main effect between classes shows a significant difference where all classes show greater score than class 11 does. This seems to support, at least ambiguously, the necessity of the I form, because class 11 does not contain any invention discussion. The lesson for class 11 consists of both E and G which upon examination must be a very confusing set of activities for a student to have without the benefit of an invention discussion. However, classes 16 and 21, which have a significantly higher score along with the others, have G as a phase alone and one must wonder how these groups were able to score significantly higher than another, which had the benefit of both the expansion and the G phase.

Table 9-18 summarizes the analysis of variance for the post-I phase. There is no significant differences between these groups showing that I does have some impact even when it is used alone as it is in classes 22 and 25. What this means

TABLE 9-17: LC-12: HEAT LAWS

ANOVA for Post G, Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Class	5	729	2.63	0.03	*
Developmental Level	1	4503	16.25	0.0001	*
Class X Level	5	311	1.12	0.35	
Error	106	277			

Least Square Means

Level	Post G	
concrete	57.1	formal > concrete
formal	70.1	

Class	Post G	
11	50.9	
14	68.0	14 > 11
16	65.8	16 > 11
21	66.3	21 > 11
22	65.1	22 > 11
25	65.5	25 > 11

TABLE 9-18: LC-12: HEAT LAWS

ANOVA for Post I, Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Class	5	136	0.37	0.87	
Developmental Level	1	3869	10.41	0.002	*
Class X Level	5	167	0.45	0.82	
Error	111	372			

Least Square Means

Level	Post I
concrete	58.3
formal	69.9

formal > concrete

Class	Post I
11	66.4
14	64.7
16	62.0
21	66.3
22	60.0
25	65.4

TABLE 9-19: LC-12: HEAT LAWS

ANOVA for Post E, Developmental Level vs. Class

Source of Variation	DF	Mean Square	F	P	
Class	5	1347	4.64	0.0007	*
Developmental Level	1	5456	18.79	0.0001	*
Class X Level	5	130	0.45	0.81	
Error	116	290			

Least Square Mean

Level	Post E
concrete	56.0
formal	69.4

formal > concrete

Class	Post E	
11	62.0	
14	51.9	
16	56.5	
21	74.6	21 > 14, 16, 11, 25
22	68.9	22 > 14, 16
25	62.4	

is that these two classes which had I alone score similarly to the other classes which had the benefit of other parts of the learning cycle albeit out of normal sequence.

Table 9-19 summarizes the analysis of variance for the post-E. Classes 21 and 22 scored significantly higher than the other classes. Since these two sections, 21 and 22, are the two which had completed learning cycles, this is evidence that all three phases are necessary.

Table 9-20 compared the post-test (CAT 4) of the control group, class 21, with the CAT 2 and CAT 3 scores of each of the six sections. This allows a comparison of all of the combinations of Table 9-2 with the control group. As is shown in the table, the complete learning cycle has a significantly higher score than any of the one and two phase learning cycles with the exception of the EI necessity X sequence variable. This is strong evidence for the necessity of all three phases of the learning cycle.

Attitude Analysis

Attitudes of students toward the learning activities utilized in learning cycle 12 were assessed by using the BAR Attitude Inventory. Table 9-21 and 9-22 contains the BAR results for the contentment factor and comprehensive factor, respectively. Students also were encouraged to write their opinion of the lessons on the back of their BAR forms. Summaries of their comments were categorized using the tally sheets which can be found in Appendix 9D.

As can be seen from Table 9-21, the classes fall into three general categories. Class 11 and 22 have the highest scores, significantly higher than class 25, and the rest of the scores fall someplace in between. In Table 9-22 the comprehension factors shows that all the classes scored significnatly higher than class 25.

Since class 25 began with the invention it might be hypothesized that this

TABLE 9-20: LC-12 HEAT LAWS

Necessity & Necessity X Sequence Variables

Compare Completed Control Sequence LC 12 CAT 4 Class 21
vs. LC 12 CAT 2 and CAT 3 of other classes.

CL	CAT	$\bar{X}$	S.D.	N	d	SE	t	df	p
21	4	75.35	18.20	20	-	-	-	-	-
22	2	59.74	27.24	19	15.61	7.46	2.09	37	**
22	3	64.67	13.91	15	9.68	5.43	1.78	33	*
11	2	63.02	17.81	21	12.33	5.63	2.19	39	**
11	3	50.88	12.52	19	24.47	4.98	4.91	37	***
14	2	52.57	22.38	17	22.78	6.78	3.36	35	***
14	3	64.94	21.48	15	10.41	6.88	1.51	33	
16	2	65.31	19.28	26	10.04	5.56	1.81	44	*
16	3	55.73	19.44	27	19.62	5.53	3.55	45	***
21	2	69.93	17.63	22	6.42	3.03	2.12	18	*
21	3	67.96	18.23	22	6.65	2.97	2.24	18	*
25	2	63.90	15.15	19	11.45	5.35	2.14	37	**
25	3	61.35	18.50	19	14.0	5.88	2.38	37	**

* = 0.10
** = 0.05
*** = 0.001

TABLE 9-21: LC-12: HEAT LAWS
ANOVA for BAR Contentment Factor, By Class

Source of Variation	DF	Mean Square	F	P	
Class	5	102	2.47	0.04	*
Error	115	41.2			

Least Square Mean

Class	Contentment	
11	27.2	11 > 25
14	25.4	
16	24.6	
21	23.7	
22	27.1	22 > 25
25	21.5	

TABLE 9-22: LC-12: HEAT LAWS
ANOVA for BAR Comprehension Factor, By Class

Source of Variation	DF	Mean Square	F	P	
Class	5	98.8	2.73	0.02	*
Error	113	36.1			

Least Square Mean

Class	Comprehension	
11	27.1	11 > 25
14	25.4	14 > 25
16	26.0	16 > 25
21	24.2	21 > 25
22	25.4	22 > 25
25	20.9	

sequence was not as desirable as the other sequences that were covered. However, if this were the case one would also expect class 22 to similarly have low scores. That this is not the case can be shown, especially for the contentment factor, since class 22 was one of the two that was significantly higher in score than class 25. The rest of the sequence with class 22, however, had the invention discussion followed by the gathering the data, which was a straightforward experiment directly connected to the invention. In contrast, class 25 had the invention directly followed by the expansion phase which was long and complex. Using this analysis, it might seem that the combination of I followed by E was an especially confusing combination which led students to be uncomfortable with the content of the learning cycle.

Even though the above discussion might distinguish between E and G as far as their ability to follow the invention phase, there is some argument that E and G might be equivalent to each other when used before and after the invention phase, for example, in the GIE or EIG sequence. This has already been discussed in a previous section concerning the CAT analysis. Given that analysis it might seem useful then to do the analysis for the BAR contentment and comprehension factors by using the combined classes. Table 9-23 and 9-24 summarizes that information. As can be seen from that analysis, there is no significant difference between the combined classes on the BAR analysis for the contentment factor. Students seem to be equally content no matter what combination of sequences are used. Table 9-24, however, does show a significant difference between class combinations. Analysis of the means of the comprehension factor seems to show that students are more confident in their comprehension in classes 11-16 (I in third phase) than they were in the classes 22-25, where the invention is used as the initial phase. Since this particular order is more characteristic of the inform-verify-practice sequence that is found in traditional classrooms, this

TABLE 9-23: LC-12: HEAT LAWS
ANOVA for BAR Contentment Factor, By Combined Classes

Source of Variation	DF	Mean Square	F	P
Class	2	46.2	1.05	0.35
Error	118	43.7		

Least Square Mean

Class	Contentment
11-16	26.0
14-21	24.3
22-25	24.0

TABLE 9-24: LC-12: HEAT LAWS
ANOVA for BAR Comprehension Factor, By Combined Classes

Source of Variation	DF	Mean Square	F	P
Class	2	136	3.66	0.03 *
Error	116	37.1		

Least Square Mean

Class	Comprehension	
11-16	26.6	11-16 > 22-25
14-21	24.7	
22-25	23.0	

result seems significant.

There were a few isolated comments concerning the logical order or sequence of the activities on the various written comments found in the BAR written responses. Some of these comments were positive, some of them were negative. There was, however, no consistent pattern which could help explain the students' attitudes toward these various sequences.

Conclusions

The major finding of this learning cycle experiment is the evidence for a sequence effect for the various phases of the learning cycle. The most favored sequences appear to be those in which the invention discussion is sandwiched between the gathering the data and the expansion phases. It does not appear to matter whether the expansion phase comes before the invention or after the invention. In other words, the gathering the data and the expansion phase seem interchangeable at least in this learning cycle. It might be argued that the expansion activities, in sequences where they come first, serve as substitute gathering the data phase activities.

There is also evidence for the necessity of all phases of the learning cycle in this experiment. By comparing different CAT examinations and different post phase information, there is evidence to indicate that all three phases of the learning cycle are beneficial to the overall learning of the concept being presented. There is especially strong evidence to indicate that the invention discussion itself plays a central role in the learning cycle although it does not seem to be able to stand alone.

The observation and case study data from this experiment seems to offer neither support nor detraction from these conclusions. Furthermore, the attitude information also is not wholly consistent with the achievement information. Students seem to prefer invention discussions coming later in the phases of the learning cycle rather than at the beginning of the learning cycle but there is no clear cut preference for the control sequences where the invention is between the G and E phases.

CHAPTER TEN

LC-14: ARRHENIUS ACIDS AND BASES

A "LESSON CONTROL" FORM EXPERIMENT

Experimental Design

LC-14 was designed to teach the concept of Arrhenius Acids and Bases. As invented during the activities of this learning cycle, the concept was stated as follows: Acids are compounds which release H^+ in water solution and bases and compounds which release OH^- in water solution. In order to teach this concept several subconcepts and skills were also taught, including: (1) acid concentration expresses the amount of acid in the solution, (2) acid strength expresses the proportion of H^+ available from an acid solution and (3) equilibrium ideas explain acid/base strength.

LC-14 was designed as a "lesson control" form experiment (See also LC-7). This means that the activities of each group was similar in content but varied in how the content was presented. In the "lesson control" form the primary source of information was varied. In the control group the source of information was the laboratory activity and the discussions. In experimental group T_1 the source of information was the teacher lecture. In experimental group T_2 the source of information was the teacher demonstration. In experimental group R the source of information was in readings. Table 10-1 and 10-2 summarize the experimental plan for manipulation of the form variable. All three phases of the learning cycle were utilized in sequence.

Two nonequivalent forms of the CAT were developed. The A form was used to test if students had prior knowledge of the content. The B form was used as a post-test and as a retention test which was given 1½ weeks after the post-test.

TABLE 10-1

LC-14 Group Assignments

Class	Assignment
11	Control
14	T_1
22	R
25	T_2

TABLE 10-2

LC-14 Testing Plan

	G	I	E		
^ pre-test Form A CAT 1				^ post-test Form B CAT 2	^ retention Form B CAT 3

Description of Classroom Activities

Learning Cycle 14 was a Form Experiment in which the variable was the form of lesson control. There were four classes used as test groups, each of which carried out all three phases of the learning cycle in the regular sequence: gathering data (G), invention (I), and expansion (E). One of the test groups was the control group. The students collected data during the G phase, organized and discussed the data during the I phase and once again collected data in the E phase. In a second test group, Teacher 1, the teacher was in control of the lesson. All of the laboratory data for G and E phases was presented by the teacher using a data array with a lecture of how the data was collected. The I phase and material from the regular learning cycle which was in the form of reading was presented as a lecture by the teacher. For the third group, Teacher 2, the teacher was in control of the lesson. The teacher conducted demonstrations of the laboratories in the G and E phases, and lectured in the I phase. The fourth test group had the material presented to them through a reading format for all three phases of the learning cycle. Classroom materials are included in Appendix 10A. The specification of classroom activities by test group and class days is summarized in the table that follows. Appropriate appendix page numbers are given in parentheses.

Post Experiment Discussion

As in previous experiments the two participating teachers and the principal investigator discussed the classroom activities of Learning Cycle 14. Assessments were based upon classroom observation and perceptions of what happened in the classroom by both observers and teachers. Since this experiment was a form experiment, its emphasis was on the control of the lesson (by lecture, teacher demonstration, readings, or experiment).

This discussion started off as an examination of the various different

TABLE 10-3

LC-14 Form "Lesson Control"

Section Day	11 Control	14 Teacher 1	25 Teacher 2	22 Reading
1	Begin G lab (10A-2)	Teacher presents data array and explanation for G (10B-4)	Teacher demonstrates G lab (10A-2, 10A-3)	G Reading, Question and answer session (10A-14)
2	Finish G lab Idea questions (10A-2 through 10A-4)	Invention Lecture (10B-5)	Invention Lecture (10B-5)	I Reading, Question and answer session (10A-15)
3	Invention discussion (10B-2, 10B-3)	Teacher presents data array and explanation for E (10B-6, 10B-7)	Teacher demonstrates E lab (10A-5 through 10A-7)	E Reading, Question and answer session (10A-6, 10A-17)
4	Expansion lab Assign questions (10A-5 through 10A-8)	Lecture over Reading 14a and 14b material (10A-9 through 10A-13)	Lecture over Reading 14a and 14b material (10A-9 through 10A-13)	Reading 14a and 14b, Question and answer session (10A-9 through 10A-12)
5	Discuss E questions, Reading 14a and discussion (10A-8 through 10A-10)	----------------	--------------	----------------
6	Reading 14b and discussion (10A-11 through 10A-13)	--------------	-------------	---------------

instructional formats used. The instructor of class 22, who had the reading group, said that he was surprised that the readings seemed to go fairly well. He felt that the students felt fairly positive about the readings because "there is a certain security in having a reading in your hand. I think it is a false security." He felt that if it were not for the fact that the readings were done in class, a lot of them would not have done them in the first place, as he felt was the case with a lot of other reading material assigned both in his class and others classes. As evidence of that he remarked that he thought that the classroom questions that came up were different questions than the questions in the other format groups. The questions indicated to him that they did not gain much from the reading itself. One of the observers felt that the class itself had deteriorated into a teacher led discussion rather than as a reading exercise. The reason for this was that the teacher would take off on student questions and used it as a basis for having a rather extensive discussion of the readings and materials associated with the readings. As a consequence, in this particular reading class, there was probably such an emphasis on the discussion/lecture that this particular format degenerated into a discussion/lecture format.

Another observer used several examples from the classroom to indicate that students pressed for experimental information and evidence to augment their information about the concept being taught. This observer said, "Students are looking for experimental evidence. They're willing to accept the teacher as an authority of what would have happened if they had done a particular experiment, but the experimental evidence is nonetheless of interest to them." The class 22 teacher agreed that the readings did probably, through post-reading discussion, degenerate into discussion/lecture and also that students did press for experimental evidence in the discussions. When asked whether these discussions were outlined and planned, he said, no, that they were extemporaneous, but that the outline of the reading itself provided a launching pad for discussion. Another observer felt, however, that this instructor was lucky in that his class seemed to be a particularly gregarious one which was willing to generate questions so that the class discussions could start. In one of the other classes, another observer indicated that the students would be asked if there were any questions and there never would be any questions. However, in this class there was always some student who would ask a question and would get a discussion rolling.

In comparing the control group with the other format groups, the observers noticed that the non-control format experiences were less dramatic and memorable to the students and as a consequence lost some of its impact. In looking at the discussion lecture section, for example, one of the instructors indicated that, "My experience with this group was that it was fine the day I presented it, but that they had no memory of it whatsoever when they finished the investigation." Another instructor said that although he had no concrete evidence, his feeling was that his demonstration group didn't have nearly the grasp on the experiment that they would have if they had done the experiment themselves. An observer indicated that when students do the laboratory they are forced to deal with the exceptions and that these exceptions help the students more firmly define the concept associated. Another observer indicated, "The demonstrations were rather uneventful. They copied down all of the stuff dutifully as was pointed out earlier, but they didn't really have as much respect for what the teacher collected as what they would have if they had collected it.

The discussants had some apprehension about the post-test and retention test which was used in this learning cycle. Since the concept was on Arrhenius acids and bases, which were defined in terms of hydrogen ions being present in water, it was felt that the test ought to assess this concept as a theoretical model of acids and bases. As a consequence, one of the examination questions had a series of chemical formulas where the acid and base nature of the compound formulas were disguised by shuffling the order in which the elements are traditionally found in the formula. This is in contrast with the traditional way of writing acids where the hydrogen atom would appear first in the formulas. Since these formulas were put in conjunction with experimental evidence, indicating the presence or absence of hydrogen ion (litmus test), it was felt that the students should identify the particular compound as being an acid or a base whether or not hydrogen appeared first in the formula. Unfortunately, many of the students seemed to be confused by this and as a consequence it was felt that they may have been so disequilibrated by this difference in formulas, that they were unable to take the test in a calm and rational manner. As a consequence, there was some concern expressed by the group as to whether the test would be valid or not.

There was some discussion as to the nature of the experimentally collected data versus simulated data sets. As was learned in an earlier chapter, data that is simulated, since it has a tendency to be cleaner and less prone to experimental and student errors, is more likely to result in valid interpretation than data that students collect for themselves. As a consequence the choice of experiments and instructional information given to students has to be carefully chosen so that the data will be clean enough to result in reasonable explanations. The instructors of this learning cycle indicated that the data that they were able to utilize in the control groups, although not as precise as the simulated data used in other formats, was nevertheless good enough so that the students were able to generate reasonable explanations.

Case Studies

One student was chosen for each of the four classes which were involved in this experiment involving Learning Cycle 14. Because this was near the end of the year, there was some difficulty with this learning cycle in having students meet the appointments for their interviews. As a consequence, our records for our case studies are incomplete. The case studies were chosen at random and do not necessarily represent the class that they came from. However, there were some useful pieces of information gained from these case studies.

Case Study 506. The teacher described this case study as a quiet student. He moved to Norman after the school year began, and although he was friendly he always seemed rather isolated in the class. He spent what seemed like a great deal of time of his written work. Because he sat right in front of the teacher, he did participate in class discussions in his quiet manner. A profile of CS-506 is found in Table 10-4.

Learning Cycle 14 was a "Lesson Control" Form Experiment. The case study was in the control test group; therefore, the learning cycle was conducted in the regular way. The normal learning cycle consisted of laboratory activities in the gathering data (G) phase, a teacher led discussion of the data in the invention (I) phase, and additional laboratory activities and readings in the expansion (E) phase. Interviews were held with the case study to determine his understanding of the concept of the learning cycle. The central concept of learning cycle 14 was that acids are compounds which release hydrogen ions in a water solution and bases are compounds that release hydroxide ions in a water solution. The following questions were asked in each of the interviews: (1) What is an acid?, (2) What is a base?, (3) How could you tell if a substance is an acid or a base?, (4) What does the term acid concentration mean?, and (5) What does the term acid strength mean? There were four interviews scheduled with this case study at various times during the learning cycle. The four interviews were pre-learning cycle (pre-LC), post-gathering data (post-G), post-invention (post-I), and post-expansion (post-E). The interviews were audiotaped. Each interview will

TABLE 10-4

CASE STUDY PROFILE

Student	506			Variable	Lesson Control
Sex	M			Group	Control
Class	11			LC 14 test scores (unadjusted)	
Grade Level	11th				
Birthday	03-07-63			CAT 1	67 %
I.Q.	-			CAT 2	56 %
GEFT[1]	-	(Quartile -)		CAT 3	- %
VH[2]	-				
FR[3]	-	5			
CC[4]	-	-			
Grades[5]	B	B	B	C	

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

2A = 1
2A/2B = 2
2B = 3
2B/3A = 4
3A = 5
3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

be summarized and excerpts from the tapes will be used to illustrate the points made in the summary. I and CS will be used to designate the comments by the interviewer and case study, respectively.

The pre-LC interview with the case study indicated that he really had no prior knowledge concerning acids and bases other than the fact that litmus paper is used to test for their presence and the formula for acids contains a H.

I: What is an acid? What is a base?

CS: All I know about acids and bases is that bases are very strong solutions...Chemically, I really don't know what they are.

I: How can you identify an acid and a base?

CS: By using litmus paper.

I: Can you recognize an acid or a base by looking at the formula?

CS: Yes, I probably could recognize it. Acids have an H at the beginning like H_2SO_4.

I: Do formulas for bases have any special characteristics?

CS: I don't really know.

I: What does it mean when I say an acid is concentrated?

CS: It means it is stronger, more reactive.

I: When I say an acid is strong, what do I mean?

CS: It is more dangerous and could react more with another substance.

I: Does it mean it is concentrated?

CS: No, it really doesn't mean the same.

During the post-G interview the case study demonstrated that he had assimilated the G phase of the learning cycle by his excellent recall of the laboratory activities. There was some evidence of accommodation. He was reluctant to state the invention but through the discussion it was obvious he had the mental structures but they were not organized. The flaw in his thoughts which may have prevented him from independently making the invention was that bases must have O^{-2} and H^{+1} rather than OH^{-}. He did not distinguish between acid concentration and acid strength.

I: Would you describe for me what you have done in class since the last time we talked?

CS: We did a lab about acids and bases. We had to describe by looking at the formula what made it an acid and what made it a base. Then we were to predict whether several substances were acids or bases. Then we went to the lab and we started to test the substances with litmus paper--blue to red is acid and red to blue is a base. We tested their conductivity. So we found out that most of the formulas that start out with H are acids and most of the formulas that end with OH are bases.

I: Most of them, are there exceptions?

CS: Not in the substances we tested.

I: What is a definition for an acid?

CS: I couldn't do that.

I: Can you give me a definition for a base?

CS: No.

I: Why did you do conductivity test?

CS: Just to test if it was a solution and to prove there were ions--that particles were broken apart.

I: How did they break up?

CS: By mixing with water.

I: Can you give me an example of an acid you had?

CS: Hydrochloric acid--HCl--and sulfuric acid.

I: Did HCl conduct?

CS: I think so. There was only one that did not conduct.

I: If it did conduct what is in your solution?

CS: Hydrogen ions and chloride ions.

I: What is an example of a base?

CS: ...calcium hydroxide.

I: Did it conduct?

CS: Yes.

I: What ions are present in there?

CS: Calcium, oxygen, hydrogen.

I: Can you identify any characteristic ions that are present in all the acids?

CS: For sure hydrogen has to be present in all the acids.

I: What about bases?

CS: Hydrogen and oxygen.

I: Did all acids and bases light up the bulb the same intensity?

CS: No, I know there were a few that were weak. I don't remember which ones.

I: How do you account for the fact that the bulb didn't light up as brightly in some?

CS: They probably didn't dissolve as well as others.

I: Are you suggesting there are less ions present in the solution?

CS: Yes.

I: When I say an acid is concentrated what do I mean?

CS: There are more ions in solution and less water.

I: When I say one acid is stronger than another, what does that mean?

CS: It means the same thing--more reactive.

During the post-I interview it was evident that the invention discussion had given the case study the definitions for acids and bases. He did have a very good memory of the laboratory activities and the discussion. He did not distinguish between a substance dissolving and a substance ionizing. The models he used for acid strength and acid concentration are incorrect.

I: Could you summarize the discussion you have in class today?

CS: We were analyzing the acids and bases. We made a list of all the acids and indicated which ones conducted and changed litmus paper. We found out all the acids have hydrogen at the front of the formula. All the acids split up into the hydrogen and polyatomic ion. So we found out acids are compounds that dissolve forming hydrogen ions which causes litmus paper to change from blue to red and to conduct. We did the same thing with bases. We found oxygen and hydrogen form an ion which conducts electricity and turn litmus paper from red to blue. So the definition for a base would be a compound made up of hydroxide, which is hydrogen and oxygen.

I: What does it mean if an acid is concentrated?

CS: There would be more hydrogen ions in the solution, plus the other type of ion. For bases, hydroxide ions.

I: When I say an acid is strong, what does that mean?

CS: It means it is more reactive. It is more concentrated. They are related.

I: How can you account for the fact that the light intensity is not the same in all of these solutions?

CS: Some solutions tend to dissolve better than others. When there are more ions present, there is better conductivity.

I: Are you accounting for that in terms of concentration?

CS: If it was more concentrated, it would have more ions present, so it would conduct better.

In the post-E interview the case study did not make any progress concerning the definitions of acids and bases. He had accommodated those ideas in the invention phase. There was a gain in his ideas concerning acid strength and acid concentration. The case study had an interesting way of describing acid concentration and acid strength.

I: Can you summarize for me what you learned?

CS: The reading explained which acid is strong and which acid is weak. In the lab we measured the hydrogen produced from different acids. So we learned by the readings and the labs that strong acids are acids that have more hydrogen present and ionize better. Weak acids are acids that are not ionized as well.

I: How did the laboratory indicate that to you?

CS: Some acids react with magnesium and produce more gas.

I: What acids did that?

CS: HCl and $HC_2H_3O_2$.

I: Which one was strong and which one was weak?

CS: We used different molarities of the acids. As the molarity increases there was more hydrogen gas produced.

I: What does that show you?

CS: That the acid is stronger.

I: What acid is stronger?

CS: It is the same acid but as the molarity increases there is more hydrogen present--dissolved better.

I: What is a strong acid?

CS: An acid that is dissolved better--ionize better--produces more hydrogen.

I: What was a strong acid in that particular experiment?

CS: 4M HCl was stronger than 1M HCl. In general, HCl was stronger than $Hc_2H_3O_2$.

I: How do you know that?

CS: From the graph--there was always more gas.

I: If I am looking at the table information, what numbers do I compare?

CS: How much gas is produced per minute.

I: Is there a difference in concentration and strength of an acid?

CS: The concentration changes and the strength is always the same. Concentration is the number of moles in solution in a certain volume. You always have the same strength of an acid.

I: What do you mean?

CS: You can have different volumes but would be the same strength. They would have a certain amount of ions in solution.

I: Are you saying you have the same number of ions no matter how concentrated it is?

CS: The more concentrated the solution the more ions there will be.

I: You indicated the strength doesn't change. How do you indicate that?

CS: By using litmus paper. Some acids dissolve better--ionize more. Test its conductivity--the brighter the light the stronger the acid.

I: Why is it stronger?

CS: Because it has more hydrogen ions--they break apart. If you have 1000 molecules--950 break apart--you have a strong acid. If you have 1000 molecules and 20 break apart--that's a weak acid.

In summary the case study was able to assimilate and partially accommodate the laboratory activities in the G phase. The invention discussion helped him organize his mental structure concerning his ideas of acids and bases. During the E phase the case study accommodated the difference between acid strength and acid concentration. The case study made significant progress in his understanding of the concept during this learning cycle.

Case Study 25. The teacher described this case study as an average student. She was interested and involved in her lessons but could also be distracted. Absences could have been responsible for a few gaps in her understanding, although she was very reliable about getting her work made up on her own time. A profile of CS-25 is found in Table 10-5.

Learning Cycle 14 was a "Lesson Control" Form Experiment. Each phase of a regular learning cycle--the gathering data (G), the invention (I), and the expansion (E)--was carried out in each test group. The variable was the lesson control. The case study was in the 'teacher lecture' test group. Therefore, the group went through each phase of the learning cycle with the lesson format being a teacher lecture. Interviews were held with the case study to determine her understanding of the concept at the various points of the learning cycle. The concept of Learning Cycle 14 was that acids are compounds that release hydrogen ions in a water solution and bases are compounds that release hydroxide ions in a water solution. There were four interviews scheduled with this case study: (1) a pre-Learning Cycle (pre-LC), (2) a post-gathering data (post-G), (3) a post-Invention (post-I), and (4) a post-Exapnsion (post-E) interivew. The interviews with the case study were audiotaped. The interviews will be summarized and excerpts from the tapes will be used to illustrate comments made in the summary. I will designate the questions asked by the interviewer, and CS will stand for the responses by the case study. The following questions were asked in each interview: (1) What is an acid?, (2) What is a base?, (3) How can we tell if a substance is an acid or a base?, (4) Explain what acid strength means to you, and (5) Explain what acid concentration means to you.

In the pre-LC interview the case study demonstrated she had very little

TABLE 10-5

CASE STUDY PROFILE

Student	25			
Sex	F			
Class	14			
Grade Level	11th			
Birthday	11-08-64			
I.Q	117			
GEFT[1]	18	**(Quartile** 4 **)**		
VH[2]	3			
FR[3]	5	4		
CC[4]	5	5		
Grades[5]	B	B	B	B

Variable Lesson Control

Group T_1

LC 14 **test scores (unadjusted)**

CAT 1 33 %

CAT 2 44 %

CAT 3 44 %

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1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.
2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6
3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.
4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).
5. Grades were given by the classroom teacher four times during the year.

knowledge of acids and bases. She had tested many substances in this course with litmus paper. She did have a good definition for acid concentration.

I: What is an acid?

CS: Something that makes the litmus paper turn from pink to blue or is it blue to pink?

I: What is a base?

CS: Just the opposite.

I: How can we tell if a substance is an acid or a base other than the litmus test?

CS: Whether it conducts...I don't know any other way.

I: Would it be possible to look at a formula for a substance and tell whether it is an acid or a base?

CS: Yeah, I'm sure it would, but I wouldn't know how.

I: What does the term acid concentration mean to you?

CS: The amount of acid in the solution.

I: Would you be a little more specific? What do you mean by amount?

CS: How much is in how much of the solution. A comparison of the two.

I: What would be meant by acid strength?

CS: The strength of the acid--how potent it was--whether it would eat through your skin.

I: Is there any difference between acid strength and acid concentration?

CS: I would think they are the same thing. If you had a concentrated acid it would probably be very strong.

During the G phase the case study began to realize that hydrogen and hydroxide ions were involved with acids and bases. However, the definitions for acids and bases were not clearly formed. Her ideas about acid concentration and acid strength were the same.

I: How can you tell whether a substance is an acid or a base?

CS: Sometimes you could tell if it had hydroxide in it.

I: When it had hydroxide in it, what did it mean?

CS: It was a base.

I: How could you tell if a substance was an acid?

CS: It didn't have hydroxide in it. It had hydrogen in it, but they all had hydrogen.

There was not a post-I interview held with this case study.

During the E phase of the learning cycle the case study assimilated some of the information from the lecture over the reading material. She had focused on the fact that concentration of an acid deals with the number of dissolved molecules and acid strength involves the number of ions present. Her definition of acids and bases was becoming more refined.

I: What is an acid?

CS: It changes litmus paper from blue to pink and usually has hydroxide or hydrogen in it. It is usually conductive.

I: What is a base?

CS: A substance which changes litmus paper pink to blue. It has hydroxide in it and an acid has hydrogen in it.

I: Will a solid base conduct electricity?

CS: No.

I: Under what conditions will it conduct electricity?

CS: When it is in a solution.

I: Is that the same for acids?

CS: Yes.

I: How can you tell if a substance is an acid or a base by looking at its formula?

CS: Whether it has hydrogen or if it has hydroxide in the formula.

I: Can you give me an example of an acid substance?

CS: Hydrochloric acid.

I: Can you give me an example of a base?

CS: Sodium hydroxide.

I: What does it mean when you talk about acid concentration?

CS: Concentration is something to do with molecules ...oh, I can't remember.

I: Tell me what acid strength means. I have a strong acid and a weak acid, what is the difference?

CS: The amount of ions...strength has to do with ions. Concentration has to do with moles per ...the amount of acid in the solution.

I: Are they the same thing or are they different?

CS: They are different.

In summary, it seems the case study was able to assimilate the information from the lectures but did not have the time or opportunity to accommodate the material. Time to accommodate the material may be one of the advantages of the student going through the laboratory activities in G and the I discussion.

Case Study 108. This student was described by his teacher as being shy. He had difficulty communicating his ideas in oral or written form, although he worked to achieve understanding of the content. Toward the end of the school year, and during this learning cycle, this case study missed school to participate in athletics. These absences had a significant negative effect of his classroom performance. A profile of CS-108 is found in Table 10-6.

The experiment, conducted during Learning Cycle 14, was a "Lesson Control"

TABLE 10-6

CASE STUDY PROFILE

Student	108			
Sex	M			
Class	22			
Grade Level	11th			
Birthday	03-27-65			
I.Q.	103			
GEFT[1]	11	(Quartile 2)		
VH[2]	5			
FR[3]	5	3		
CC[4]	2	6		
Grades[5]	B	B	B	C

Variable	Lesson Control
Group	R
LC 14	**test scores (unadjusted)**
CAT 1	56 %
CAT 2	51 %
CAT 3	33 %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

form experiment. The section, of which this case study was a member, utilized readings for all phases of the learning cycle. Scheduling conflicts prevented interviews after each phase of the learning cycle, but three interviews were conducted. One interview was held prior to the start of the learning cycle (pre-LC), the second interview was held midway through the expanding the idea phase (mid-E), and the final interview was held at the end of the learning cycle (post-E).

Learning Cycle 14 was concerned with the Arrhenius definitions of acids and bases. The main invention was this definition for acids and bases. The interviews involved questions designed to elicit the case study's understanding of the definitions and properties of acids and bases. Acid concentration and acid strength were subordinate ideas that were dealt with in the learning cycle and the interviews.

During the pre-LC interview, the case study knew that acids and base affected litmus paper, but he knew little else about them. He had a qualitative sense of concentration, and his description of acid strength related to damage to objects by the acid--a reactivity model.

I: What is an acid?

CS: (The case study was unable to respond)

I: What is a base?

CS: (no response)

I: Could you tell me how to identify an acid in the laboratory?

CS: Test it with litmus paper.

I: What about bases?

CS: Same thing.

I: Looking at the formula for a molecule, could you tell me if it was an acid or base?

CS: I don't think I could.

I: When I say that an acid is concentrated, what does that mean?

CS: There's so much in a certain area; it's not just right there, it's all through something instead of being in one spot.

I: When I say that an acid is a strong acid, what does that mean to you?

CS: It's very powerful. Get it on something and it will probably eat a hole through it.

The case study had gathered acid and base definitions from the readings, but the base definition that he demonstrated during the mid-E interview was incorrect. His definitions of acid concentration and acid strength had not changed appreciably, although his statement about concentration contained an added quantitative aspect. He stated a mistaken idea about strong and weak acids.

I: What is an acid?

CS: The reading said that most acids contain hydrogen as H^+.

I: What is a base?

CS: It can contain hydrogen, but it usually doesn't, and the hydrogen is minus.

I: What does it mean when I talk about a concentrated acid?

CS: Like in 100 ml of water, you would have more of that acid there. It's just a lot of acid for a certain amount.

I: When I say I have a strong acid, what does that mean to you?

CS: It's how powerful it is.

I: What is the difference between concentration and strength, or are they the same thing?

CS: I guess it would be that acid concentration is how much there is in a certain area, and acid strength is how powerful it is.

I: What do you mean by powerful?

CS: The strength of it; like certain acids will eat through things faster.

I: Can you give me an example of a strong acid and one that would not be so strong?

CS: The acids in your stomach are weak, and I don't know a strong acid.

During the post-E interview, the case study had accommodated to a more theoretical idea of acid strength. He had partially corrected the misconception he had of bases, but he seemed to be rather uncertain about his definition

I: What is a strong acid?

CS: An acid that ionizes well; that releases hydrogen very well. It doesn't have a strong attraction on it.

I: Is it possible for an acid that is two molar in concentration to be stronger than an acid that is five molar in concentration?

CS: Yes. The two molar concentration would lose its hydrogen quicker, because there is less attraction than the one with five.

I: What is an acid?

CS: Two atoms that combine with hydrogen, and, when you dissolve it in water, its hydrogen atoms will break back up.

I: What is a base?

CS: It's the same thing, except when a base breaks up, the hydrogen will be a negative charge, and it will usually have oxygen with the hydrogen so it will be like OH with a negative charge.

The reading format was pleasing to this case study because he was able to make up his missed work rapidly. In reading the content of the learning cycle, however, he concluded his study with some misconceptions remaining. He had accommodated to reasonably good ideas of concentration and strength of acids, and his definition of an acid was acceptable, although he wavered during the post-E interview.

Case Study 117. This student was described by his teacher as being consistently distracted by his involvement in extracurricular acitivites. He occasionally missed class to engage in some activity, and, when in attendance, he often napped. Occasionally, though not regularly, he would engage in class discussions to the benefit of the group. A profile of CS-117 is found in Table 10-7.

The experiment, conducted during Learning Cycle 14, was a "Lesson Control" Form Experiment. The section, of which this student was a member, had all experiments performed by teacher demonstration. Only two interviews were conducted with this case study--one before the learning cycle (pre-LC) and one at the end of the learning cycle (post-E)--because of interview scheduling conflicts.

Learning Cycle 14 was concerned with the Arrhenius definitions of acids and bases. The main invention was this definition for acids and bases. The interviews involved questions designed to elicit the case study's understanding of the definitions and properties of acids and bases. Acid concentration and acid strength were subordinate ideas that were dealt with in the learning cycle and the interviews.

During the pre-LC interview, this case study seemed to feel a compulsion to answer questions at length, even if he did not have any pre-formed ideas about the questions. He had misconceptions and/or erroneous memories about everything asked in this interview from the color of litmus paper to the strength of acids. Regarding acid strength, it appeared that the student may have had some sort of acid-base neutralization model that he was attempting to use to explain strength. It is possible, though purely speculative, that he was recalling the opposite effect of acids and bases on litmus paper--a phenomenon observed many times in the laboratory--to arrive at this model.

TABLE 10-7

CASE STUDY PROFILE

Student	117			
Sex	M			
Class	25			
Grade Level	11th			
Birthday	06-27-65			
I.Q.	107			
GEFT[1]	10	(Quartile 2)		
VH[2]	4			
FR[3]	3	3		
CC[4]	5	5		
Grades[5]	B	A	C	B

Variable Lesson Control

Group T_2

LC 14 test scores (unadjusted)

CAT 1 67 %

CAT 2 56 %

CAT 3 - %

1. A discussion of the Group Embedded Figures Test (GEFT) can be found in Chapter 2.

2. This is the Volume Heaviness task of the SRT (See Chapter 2). The scores translate into Piaget levels according to the following scale:

   2A = 1
   2A/2B = 2
   2B = 3
   2B/3A = 4
   3A = 5
   3B = 6

3. This is the Flexible Rods task of the SRT (see footnotes 2 for scale). It was given twice: in September, 1981, and April, 1982.

4. This is the Chemical Composition task of the SRT (footnotes 2 and 3).

5. Grades were given by the classroom teacher four times during the year.

I: What is an acid?

CS: That's the one that changes litmus paper from pink to green or green to pink. I'm not really sure which one is correct.

I: What is a base?

CS: When it doesn't change litmus paper.

I: Is there any other way to tell an acid or a base?

CS: Conductivity might have an effect. If it conducts, it might be an acid, and if it doesn't, then it's a base, but I'm not really sure about that test.

I: If I have a formula for a substance, can I tell if it is an acid?

CS: Like it was NaOH? I guess if you knew which elements were bases and which were acids, and you put two acids together, then you could presume they would still be an acid.

I: What is meant by acid concentration?

CS: It probably has something to do with how much acid it contains in so many milliliters or liters.

I: What is meant by acid strength?

CS: Probably how strong it is, and I guess if you put it through some kind of chemical reaction, or so, with a base, if it turns into a base or not depends on the acid strength. If it's going to turn into another content, or something, you're going to see how strong it is, and if it's strong, then it won't change as much, but if it's kinda weak, it might change.

I: Do you think acid concentration and acid strength mean the same thing, or are they different?

CS: They probably relate in some way. They have some type of relationship, but I'm not sure if they're the same or not.

The case study still retained some serious misconceptions, but he had corrected his definition of an acid and a base as it relates to change in litmus color by the post-E interview. He maintained the same model for acid strength, as in the pre-LC interview.

I: What is an acid?

CS: An acid turns litmus paper from blue to pink, and an acid is an acid depending on how much hydrogen a compound has, and it always conducts electricity or it doesn't always conduct. I'm not sure. I always get the two mixed up between acids and bases.

I: If I have a formula like H_3BO_3, is that an acid because it contains hydrogen?

CS: Well, it doesn't mean that every compound with hydrogen is going to be an acid. It depends on whether it dissolves, and how much hydrogen discharges with ions.

I: What is a base?

CS: A base turns litmus paper from pink to blue, and depends on how many hydroxide ions are in the compound.

I: What is meant by the term acid concentration?

CS: Acid concentration is how much hydrogen is contained in the system--how much it will give off--and if it releases a lot of hydrogen ions, you say it has a high acid concentration.

I: What do you mean by hydrogen being released?

CS: If it's given off as a gas, or if it reacts with another substance in a reaction.

I: Are you saying that an acid is concentrated if it releases hydrogen gas?

CS: Yeah, kinda part of it. Also, if it reacts with the other compounds to make HCl, or something.

I: What is meant by acid strength?

CS: How strong the acid is. If you mix it with another substance or if you try to make it react with something else, if it remains an acid after the reaction then it has a high acid strength. If it doesn't, then it will probably be relatively low.

I: What is meant by a 0.4 molar solution?

CS: It's the amount of solution per liter, or something like that, and four tenths means you have that much grams over milliliters.

In the post-E interview the case study made an attempt at definitions for acids and bases that contained theoretical aspects. He had assimilated that there was a litmus criterion, an element criterion, and a conductivity criterion, but he had not been able to put these criteria into an organized structure. Other than these assimilations, the case study seemed to have gone through the learning cycle without profit.

Summary. The most important outcome from these case studies, is evidence of self-generated invention that is found in case studies 506 and 25. In both of these cases there seemed to be some evidence during the post-G discussion that the student had some gains over the pre-learning cycle discussion. The indication here is that although the invention is incomplete, there did seem to be some evidence that some invention went on during the G phase. It would appear in both of these cases that the role of the invention discussion itself is to solidify and give a language to these inventions. Another hypothesis generated out of these case study discussions was that reading and other non-laboratory formats do not allow the time necessary for the development of ideas. Perhaps one of the roles of the experiment is to give students enough time to assimilate the information necessary for the invention of the concept during the following discussion.

Achievement Analysis

The two versions of the CAT analysis used in assessing achievement for this learning cycle can be found in Appendix 10C. The grading criteria for use with

TABLE 10-8: LC-14: ARRHENIUS ACIDS AND BASES

ANOVA for CAT 1, Developmental Level by Class

Source of Variation	DF	Mean Square	F	P	
Class	3	200	0.79	0.51	
Developmental Level	1	895	3.52	0.07	*
Class X Level	3	815	3.2	0.03	*
Error	63	254			

Least Square Means

Class	Concrete	Formal	
11	50.0	37.3	
14	37.7	50.7	14,22,25 f > 11 f
22	43.0	59.0	
25	38.7	51.8	11 c > 11 f 22 f > 22 c 25 f > 25 c

these CAT tests is also found in Appendix 10C. The two versions are not equivalent. The first versions of the examination was used merely to judge the equivalency of the classes as far as pre-learning cycle information of the concept, to see whether the relative amount of information contained was negligible, and to check if all the classes had an equal amount of knowledge. The same test was used for the post-test and for the retention examination.

The pre-test results between classes and by developmental level can be found in Table 10-8. As can be seen there is no main effect difference between classes. However, there is a main effect difference between developmental level and an interaction effect of class by level. A Newman-Keuls test shows that these differences are associated with class 11 whose formal students are found to score significantly lower than the formal students of classes 14, 22, and 25. There are also significant differences between the concrete and formal students in classes 11, 22 and 25. One odd effect here is that the concrete students in class 11 actually scored better on the pre-test than the formal students did. Because of these significant differences it was felt that two analyses of the rest of the CAT evaluations should be done; one where no covariant was used and another where the pre-test would be used as a covariant. It was felt that there might be some danger in doing this since the pre-test was not an equivalent test to the post or retention test, but a comparison of the results still seemed reasonable.

It can also be shown on Table 10-8 that there is some pre-knowledge of the concept that is being carried into this learning cycle. This seems reasonable from the point of view that students have been introduced to acid and base behavior prior to this learning cycle, although their knowledge has been limited to an operational definition of acids and bases based on laboratory tests.

Tables 10-9 and 10-10 summarize analysis of variance for the post-test

TABLE 10-9: LC-14: ARRHENIUS ACIDS AND BASES

ANOVA for CAT 2, Developmental Level by Class

Source of Variation	DF	Mean Square	F	P
Class	3	812	3.00	0.04 *
Developmental Level	1	2004	7.41	0.008 *
Class X Level	3	320	1.18	0.32
Error	75	270		

Least Square Means

Class	CAT 2	
11	61.4	11 > 14
14	48.8	
22	61.6	22 > 14
25	64.3	25 > 14

TABLE 10-10: LC-14: ARRHENIUS ACIDS AND BASES

ANCOVA for CAT 2, Developmental Level by Class, with pretest as covariate

Source of Variation	DF	Mean Square	F	P
Pretest	1	1329	5.10	0.03
Class	3	978	2.73	0.05 *
Developmental Level	1	1103	4.24	0.04 *
Class X Level	3	268	1.03	0.39
Error	59	260		

Least Square Means

Class	CAT 2	
11	63.5	11 > 14
14	49.1	
22	63.1	22 > 14
25	63.8	25 > 14

developmental level by class. In studying Table 10-9, it can be shown that there is a main effect involving class. A study of the Newman-Keuls test shows that classes 11, 22, and 25 score significantly higher on the post-test than class 14 does. There is also a main effect involving developmental level with formal students scoring higher than concrete students. Table 10-10 has the same analysis but using the pre-test as a covariant. A study of the results here shows that the pre-test does significantly act as a covariant in this particular case, but that the pattern of scores are the same. In summary, classes 11, 22, and 25 score significantly higher than class 14. In order to try to explain this phenomenon it is useful to look for commonalities between the classes 11, 22, and 25. In studying these it appears that all three of these classes depended upon a discussion rather than a lecture format during the invention phase of the learning cycle. Section 22, which was a reading section, was designed originally not to have a discussion, but, as was discussed earlier in the observation section, the students forced a discussion of this material by their teacher during a question answering period. Section 14 in contrast was a strict lecture section and the students did not involve the teacher in a discussion during the invention phase of this learning cycle.

Table 10-11 summarizes the retention test data. Because this learning cycle was taught very late in the year it was necessary to give the retention test only 1½ weeks after the end of the learning cycle. As can be seen from the analysis of variance, there is a significant difference between classes which is summarized using the Newman-Keuls test as class 11 having a significantly greater score than either class 14 or class 22. In summary, the control which consisted of lab/discussion had significantly better scores than either the lecture or the reading formats. The demonstration formats lie someplace between these two groupings. Table 10-12 shows that the pre-test does act as a covariant

TABLE 10-11: LC-14: ARRHENIUS ACIDS AND BASES

ANOVA for CAT 3, Developmental Level by Class

Source of Variation	DF	Mean Square	F	P	
Class	3	707	2.38	0.08	*
Developmental Level	1	810	2.73	0.10	*
Class X Level	3	564	1.90	0.14	
Error	74	297			

Least Square Means

Class	CAT 3	
11	63.2	11 > 14, 22
14	52.7	
22	50.4	
25	59.2	

TABLE 10-12: LC-14: ARRHENIUS ACIDS AND BASES

ANCOVA for CAT 3, Developmental Level by Class with Pretest as Covariate

Source of Variation	DF	Mean Square	F	P
Pretest	1	1029	3.41	0.07
Class	3	602	1.99	0.12
Developmental Level	1	264	0.88	0.35
Class X Level	3	429	1.13	0.34
Error	59	301		

Least Square Means

Class	CAT 3
11	64.0
14	53.6
22	51.1
25	61.3

for this learning cycle and virtually eliminates the significant differences that were noticed without the covariant for class differences. However, the pattern of the scores are the same with class 11 scoring higher than either 14 or 25 with class 25 score lying someplace in between.

Table 10-13 shows the gain scores between post-test and retention for the four experimental classes. As can be shown by that table, once again there is differences between classes with class 11, which is the control group, and 14, which is the lecture section, scoring significantly higher than the reading group. Once again, the demonstration is someplace in between.

In summary, there is evidence that the formats associated with laboratory and discussion are superior to reading and lecture formats in so far as short term learning of the material. There is also indication that the lab/discussion format and also the lecture format are better than reading formats in maintaining the gains of the learning for a longer period of time. The demonstration format seems to be someplace in between in effectiveness between reading and laboratory discussion formats.

Attitude Analysis

Attitudes toward learning cycle 14 in the formats of the various groups of the experiment were assessed in two ways. The BAR Attitude Inventory was utilized at the end of the learning cycle as it had been in previous experiments. Students were invited to put spontaneous evaluation comments on the back of their BAR forms and tally sheets summarizing the nature of those comments can be found in Appendix 10D.

The analysis of variance for the BAR inventory contentment factor is found in Table 10-14. As can be seen, there is a significant difference between classes associated with this test. However, the Newman-Keuls failed to turn up significant differences between groups. This indicates that the variation is

TABLE 10-13: LC-14: ARRHENIUS ACIDS AND BASES

ANOVA for Gain Score (Retention-Post test),
Developmental Level by Class

Source of Variation	DF	Mean Square	F	P
Class	3	594	2.77	0.05 *
Developmental Level	1	231	1.07	0.30
Class X Level	3	61	0.28	0.88
Error	70	215		

Least Square Means

Class	Gain Scores	
11	0.84	11 > 22
14	0.83	14 > 22
22	-10.8	
25	- 4.8	

TABLE 10-14: LC-14: ARRHENIUS ACIDS AND BASES

ANOVA for BAR, Contentment Factor

Source of Variation	DF	Mean Square	F	P
Class	3	100.2	2.41	0.07 *
Error	78	41.6		

Least Square Means

Class	Contentment
11	25.8
14	22.4
22	24.9
25	21.2

TABLE 10-15: LC-14: ARRHENIUS ACIDS AND BASES

ANOVA for BAR, Comprehension Factor

Source of Variation	DF	Mean Square	F	P
Class	3	31.6	0.77	0.52
Error	78	41.1		

Least Square Means

Class	Comprehension
11	23.4
14	23.5
22	22.8
25	20.9

split equally between the four classes, but is not concentrated enough so that one class stands out. In studying the means, it can be seen that the control group has the highest contentment score with the reading group a close second. The lecture and demonstration classes have scores which are slightly lower. Remembering that the reading class degenerated into a discussion, there is some indication that discussion information is viewed as contributing to the students' contentment with their learning in the learning cycle.

Table 10-12 shows that there is no differences between classes concerning students' confidence in their comprehension of the material taught by the learning cycle.

The written comments from class 11, which had the laboratory, indicated a large number of positive comments concerning the laboratory and a moderate number of negative comments concerning the questions in the readings, which were a part of the lesson in the expansion phase. The written comments from section 14 were few in number. There were a small number of comments indicating a need for laboratory work. Section 22 indicated some interest in the demonstration indicating that the teacher was goaded into doing a demonstration in this particular lesson which was a reading group. One student commented, "I like the demonstration in class, but there needs to be more ordered class discussions." Group 25 which was the demonstration group also indicated some positive comments toward the demonstration, but also some indication that they would like to see some laboratory work being done. A larger number of students in all the groups indicated a certain amount of confusion associated with this learning cycle. Part of this confusion may be accounted for by the relative difficulty of the post-examination which was used and was discussed earlier in the observation section. This may have undermined the students' confidence in understanding the material of the learning cycle.

Conclusions

This learning cycle gives evidence favoring formats utilizing laboratory and discussion techniques. It especially shows the favor of these formats over reading and lecture formats. It also indicates that the students during learning cycles expect experimental information and will sometimes force the teacher to discuss experimental information and experimental description even if it doesn't exist in the design of the lesson format. Finally, there is continued information that reading formats are not consistent in their ability to teach students. At the very least, reading formats cannot stand alone for students in our experimental samples. Without the support of lecture, discussion, or laboratory work the reading material seems to be completely ineffective as a learning tool.

CHAPTER ELEVEN

EVALUATING THE VARIABLES IN THE RESEARCH

The main focus of the research described in this volume was to understand how the learning cycle approach works in the area of high school chemistry. In order to study this problem three variables were identified and manipulated. The first of these variables, termed the necessity variable, was utilized to see whether all three phases of the learning cycle were necessary for the optimum learning of the content taught by the learning cycle activities. The second variable, the form variable, was investigated by changing the format of the activities in the various phases of the learning cycle. For example, readings or demonstrations might take the place of discussions and laboratories which were part of the normal learning cycle procedures. Finally, the sequence variable investigated whether the order in which the learning cycle phases were utilized had an effect on the learning of the concepts in the learning cycle activities. It was felt that by investigating these three variables insights into the workings of the learning cycle, and assessments of the format and value of the various phases of the learning cycle, could be carried out.

Five kinds of information were utilized in order to evaluate the effect of these three variables. Achievement was measured by using the Content Achievement Tests (CATs). These tests and their design were explained in more detail in earlier chapters of this report. Attitudes were measured using the Birnie-Abraham-Renner (BAR) Quick Attitude Inventory. In addition to this quantitative information, qualitative data were also obtained through classroom observations, interviews with case studies, and the utilization of evaluative comments written by students. The data used in evaluating three variables were presented in detail in Chapters 4 through 10. This Chapter will summarize those data and try to present some conclusions relative to the necessity, sequence and form variables.

The Necessity Variable

Achievement, as measured by the CATs, was used to evaluate the necessity of the three phases of the learning cycle in four different experiments involving Learning Cycles 2, 5, 8, and 12. The specific information on these learning cycles can be found in chapters 4, 5, 7, and 9, respectively. Two different strategies were used to evaluate the necessity of the phases of the learning cycle. The first of these was reflected in experiments involving Learning Cycle 5 and Learning Cycle 8. The strategy of these investigations was to eliminate one of the phases of the learning cycle and then to compare student learning with the control group. The three phases of the learning cycle are the gathering the data phase, the invention of the concept phase, and the expansion of the concept phase, termed G, I, and E, respectively. In these necessity experiments, three experimental groups (GI no E, GE no I, and IE no G) were compared with the control group for which all three phases (GIE) were present.

The second strategy utilized to evaluate the necessity of the various stages of the learning cycle was carried out in Learning Cycle 2 (Chapter 4) and Learning Cycle 12 (Chapter 9). The strategy in this case was to utilize the CAT examinations after each phase of the learning cycle. By comparing the tests given after the first or second phase of the cycle and comparing them to completed learning cycles, it was possible to see what the effect of eliminating one or more of the learning cycle phases had on the learning of the students. Since these particular learning cycles were mainly used as sequence tests, some of the experimental groups which had the learning cycle phases out of sequence had to be eliminated in order to exhibit a pure manisfestation of the necessity variable.

Some potentially confounding factors had to be considered when interpreting the data on necessity. The first of these was what might be called a compensation factor. It seemed that some students were able to compensate for lack in a particular lesson by either studying more diligently or picking up information from other sources in order to make-up for the fact that the lesson itself was deficient. This left open the possibility that, although an experimental group might be found to be no different statistically than the control group, the lesson approach might still be less than ideal as an instructional strategy. Another compounding factor concerned the role of the E phase of the learning cycle. There was evidence, which was explained in detail in earlier chapters of this report, that the E phase might have acted as either a self-contained learning cycle in minature or as a substitute for the G phase. As a consequence, the E phase might have been used by the students to compensate for missing phases in the necessity experiment. This will be discussed further when the sequence variable results are reported. There was also the tendency for students to make up for missing information by asking questions which forced the teacher to supply information that would have been found in a missing phase.

Another factor concerned the differences between concepts. Some concepts because of their difficulty or other characteristics seemed to lend themselves to being learned more easily than others. Also even though this is a first course in chemistry, some chemical knowledge may have been gained by students through past experience.

Taking these various potentially confounding factors into account, the discussion will now focus on judging the necessity of the three phases of the learning cycle. The information used to assess if any of the three phases could stand alone is found in Learning Cycles 2 and 12. From Table 4-22 there is no evidence that the complete learning cycle, as represented by the control group, is better than any of the phases of the learning cycle taken alone. In view of the fact that this same table offers evidence that the completed learning cycle is better than combinations of two phases of the learning cycle, there is reason to discount this information. In addition, information from Learning Cycle 12, Table 9-20, shows that the control group is significantly better than any of the phases taken alone. These same tables from Learning Cycles 2 and 12 can also be used selectively to judge the GI, GE, and IE phases versus the control group, GIE. From these data with Learning Cycle 2, the control group is significantly better than the GI or the IE phases showing the necessity of the E phase and the G phase of the learning cycle. There is no evidence from Table 4-22, however, that the control group is better than the GE phase. From the previous discussion, however, it has been shown that the E phase might serve to compensate for a lack of the I phase. Table 9-20 shows that the control group is better than any of the two phase examples in Learning Cycle 12. These data show that all three phases are a necessary part of a complete learning cycle.

From Learning Cycle 5, Table 5-9, it can be seen that the completed learning cycle has higher scores than the GI combination; however, there is no evidence that it is better than the GE or the IE combinations. Once again, taking into account the possibility of the compensation factor of the E phase, this result is easier to understand. From Table 7-11, (Learning Cycle 8), evidence of the control group superiority over the GI combination is shown. The most clear evidence from these two necessity experiments is for the necessity of the E phase of the learning cycle. The trend analyses, illustrated in Table 4-21 for learning cycle 2 and 9-10 for learning cycle 12, are inconclusive. The weight of the evidence from these four experiments, however, is for the necessity of all three phases of the learning cycle, with special emphasis on the E phase (expansion phase) playing a more important role than might previously have been thought.

Interestingly enough, the attitude measures from the BAR inventories for Learning Cycle 5 and Learning Cycle 8 are more ambiguous. From Table 5-11 it can be seen that students in the control group (completed learning cycle) show more positive attitudes than students in the GI combination group. There is no evidence that any of the other two phase combinations are less thought of by the students. From this information it would seem that the E phase is critical to the students attitudes toward a learning cycle. In contrast, from Table 7-13 and 7-14, the GI phase is more highly thought of than either the control group or the other two-phase combinations that involve the E phase. In this case, the one combination that does not include the exploration is more highly thought of than any of the combinations that include it. This must be interpreted as a difference between the concepts themselves and not how they were taught. There is evidence from observational data that the E phase in Learning Cycle 8 was extremely complicated and drawn out, and as a consequence may have resulted in confusion. Therefore, although the E phase may be critical for learning concepts, students do not have a positive attitude toward it in this learning cycle.

The conclusions drawn about the necessity of the three phases of the learning cycle are consistent with the high school physics results which are discussed in a companion volume to this report. In general, all three phases of the learning cycle are necessary to optimum learning of chemistry and physics concepts.

The Form Variable

This variable was used to test whether the form of educational materials would effect learning during a learning cycle lesson. Four formats were investigated. The control format consisted of the normal formats used during a learning cycle. This could be characterized as a laboratory/discussion format. Other formats used in the experimental groups utilized readings, teacher demonstrations, and lectures. The demonstrations and lectures could be characterized as teacher controlled lessons, whereas the readings were controlled by written materials. The normal learning cycle format was a shared control between the student and the teacher.

Three learning cycles were used to investigate this variable. They were Learning Cycle 7, which was discussed in Chapter 6, Learning Cycle 14, which was discussed in Chapter 10, and Learning Cycle 10 which was discussed in Chapter 8. Two slightly different versions of the form variable were tested. Learning Cycles 7 and 14 were termed "lesson control" form experiments. In these cases, the lesson was controlled by the readings, demonstrations, lectures, or laboratory/discussion forms through all three phases.

In Learning Cycle 10, which was a "data presentation" form experiment, only in those elements of the learning cycle where data were presented to students was there a variation in form. Since data were presented in the gathering the data phase (G) and the expansion phase (E), the lecture, demonstration, reading or laboratory/discussion was found only in those phases. The invention phase was consistent through-out all groups and was a discussion of the data which were presented in the G and E phases.

A summary of the CAT results for Learning Cycle 7 can be found by referring to Tables 6-12 and 6-13. From this information, the laboratory/discussion was more effective than the reading format for concrete operational students, and the opposite was true for formal operational students. There was not much evidence to distinguish among the other formats. For Learning Cycle 14, Tables 10-10 and 10-11 showed that the control group (laboratory/discussion group) was more effective than either the lecture or the reading groups. The data were inconclusive for the demonstration groups. Learning Cycle 10 was inconclusive over-all. A possible extenuating circumstance which might explain the lack of results in Learning Cycle 10 was the poor results that students obtained from the laboratory portion of this exercise.

From an attitudental point of view, learning cycle 7 showed that the students in the lecture/discussion and demonstration formats were more pleased with the lesson than those involved in readings; and in Learning Cycle 14, the laboratory/discussion and reading groups were more content than those in either the demonstration or lecture group. Learning Cycle 10 was once again inconclusive in distinguishing among the groups.

In summary, on balance it appears that the laboratory/discussion group was especially effective for concrete operational students. Formal operational students seemed to find the reading format effective for some learning cycles. Over all, neither concrete nor formal students appeared to care very much for reading formats.

In comparing these results with the high school physics group described in the companion volume of this report, the achievement evidence is more obvious in the chemistry than in the physics results. The physics group found more attitudental evidence favoring the laboratory/discussion. One possible explanation, for the physics group difficulty in finding achievement information to support the superiority of the laboratory/discussion formats, might be a preponderance of formal operational students found in the physics classes versus the larger percentage of concrete and transitional students found in the chemistry classes. This is especially evidenced in Learning Cycle 7 by the contrast between the effectiveness of reading and laboratory/discussion groups depending upon whether students are concrete or formal. This is also seen in all three of these learning cycles comparing formal operational versus concrete operational students on the pre, post, and retention tests. In almost every case the formal operational students scored better than the concrete operational students on all of these examinations (CAT) (See Tables 7-8, 7-9, 7-10, 8-9, 8-10, 8-11, 10-8, 10-9, 10-10, and 10-11).

Sequence

The sequence variable was investigated in Learning Cycle 2 (Chapter 4) and Learning Cycle 12 (Chapter 9). There were six possible sequences of the three phases of the learning cycle and these were assigned to different groups. The control group, the GIE sequence, was considered the ideal sequence from a theoretical point of view.

It was argued earlier that there was some evidence, especially coming from the interviews and classroom observations, that the expansion phase (E) served a special role in the learning cycle. There was evidence that it could have served two functions. One possibility was that since the expansion phase contained both investigations and discussions and reading activities, it might have served as an intact learning cycle within the phase itself. There was also an indication that the E and G phases might be interchangeable, depending upon the position of the phase in the learning cycle. A possible explanation for this result might be the reasoning patterns that are represented by the learning cycle. Since the concept, is induced from information presented in the G phase in the normal sequence, the G phase information is used in an inductive reasoning pattern when the information is discussed during the invention phase. The invented concept is then used to deduce new ideas during the expansion. These new ideas might be utilized for the support of the concept, limitation of the concept, or wider application of the concept. In this particular example, G might be basically inductive and E might be basically deductive in reasoning patterns by virtue of their position in the sequence. If the E phase came first, as a replacement for G, it would then be used to induce the concept. G which might follow the invention could then, by virtue of its new position, become basically deductive in nature. As an example, in Learning Cycle 12, the heat laws, the G activity has students measure heats developed from a physical change. The teacher and the students then invent the idea of heat energy transfer through a physical change using a "heat of solution" argument. The E phase activities measure heat again, this time using a chemical reaction rather than a physical change. But this difference may be too subtle for students, and using E first does nothing more than give the first example of heat transfer in a chemical sense rather than a physical sense. As a consequence, in Learning Cycle 12, the E and G phases may be interchangeable. Because of this, equivalent classes were combined for a reanalysis of the data. The issue was not so much on the position of the E or G phases as it was on the position of the invention phase. In these experiments, the invention phase might come first before the G and E phase, it might be sandwiched between the G and E phases, or it might come last.

In Learning Cycle 2, the achievement tests summarized in Tables 4-13 and 4-14 indicate that all sequences except for the IEG sequence were better than the control group sequence, GIE. The trend analyses, as shown in Tables 4-10 and 4-11, showed no real pattern that could be explained as a sequence effect. The composite classes, however, did indicate that there was some advantage in a sequence where the invention came last. This particular sequence seemed to be superior to both the invention first or the invention second phase, for concrete operational students. For formal operational students, in contrast, there did seem to be some advantage to the invention coming first. However, because of difficulties with Learning Cycle 2, which was the first experiment done in the school year, these results might be considered suspect. Several factors had to be taken into account. First of all, the control group had inflated pre-test scores. There was also some evidence that the concepts which were taught in this learning cycle might have been part of the students' previous knowledge, gained from other classes. The consequence of this was that this learning cycle might have been perceived by the students as an expansion or review of the concept, rather than as a lesson on a new concept.

The results found in Learning Cycle 2 seemed to be contradicted by Learning Cycle 12 which showed a definite sequence effect. This was indicated in Tables 9-9 and 9-10. This was also the case with the combined classes where the evidence for sequencing was very strong as shown on Tables 9-11 and 9-12. These results were supported by the trend analyses where the control group was the only combined class group that show the build-up of knowledge across time. This is shown in Table 9-15. These results seemed to further support the idea of the interchangeability between the E and G phases.

The attitude data collected in Learning Cycle 12 seemed to support sequences where the I phase came later in the activity, but there were no clear-cut results favoring whether the I should be last or between the E and G phases. No attitude data were collected for Learning Cycle 2.

In conclusions there was strong evidence in Learning Cycle 12 for a sequence effect favoring the invention phase coming after the laboratory activities and before follow-up activities. However, this conclusion is contradicted by, a perhaps flawed, Learning Cycle 2 experiment.

In comparsion with the physics group, there is some support favoring a sequencing effect in the attitude data. However, there was no real achievement support from the physics groups. Perhaps all this proves is that the achievement of formal operational students in contrast to concrete operational students is not effected by the sequence of activities and seems to be able to adjust to a variety of instructional presentations.

CHAPTER TWELVE

SEQUENCING LANGUAGE AND ACTIVITIES IN TEACHING HIGH SCHOOL CHEMISTRY

The title of this volume and also of this chapter concerns three areas of instruction: sequencing, language, and activities. Although the evidence associated with many of the educational issues associated with these three areas was discussed in the previous chapter, and in Chapters 4 thru 10 before that, it was felt that it might be useful to look at these issues with a slightly different focus; a focus which might cut across each of the individual experiments concerning the sequence, necessity and form variables. It was also felt that in addition to the data that were collected and reported upon in esrlier chapters, that it would be useful to tap another source of data which was only lightly utilized in the earlier analyses. This consists of the written comments that were spontaneously developed and recorded by students on the reverse side of the BAR inventory forms. These comments were categorized in two different ways and a summary of the categorizations can be found in the D appendicies of Chapters 5 thru 10.

The discussion of this chapter will concern itself with sequencing, activities, and language. Sequencing was discussed thoroughly in an earlier chapter and will only be augmented in the discussion in this chapter. Language will be discussed in two different formats: language associated with written material (readings), and language as it presented itself in lecture/discussion formats. Finally, activities will be discussed in terms of laboratory.

Sequencing

The conclusion to be gained from the discussion in Chapter 11 concerning the sequence variable is that the sequence of the phases of the learning cycle is important. In discussing the details of that information, several conclusions can be drawn. First of all, the most important phase of the learning cycle, when considering the sequencing variable, is the invention phase. It is the position of the invention phase that is important to optimum learning. That is, whether the invention phase comes first, last, or in the middle position in the sequence of the learning cycle. There is plenty of evidence supporting the interchangeability of the gathering the data and expansion phases. Detailed discussion of this information was found earlier. Although sequence is important, there does not seem to be any one sequence that is best in all circumstances. From the data collected, it seems to depend upon whether the concept being taught is a new concept or one with which the student has had previous exposure. If the concept is a review concept, the optimum sequence of the learning cycle phases is different, depending upon whether students are concrete or formal operational. If students are concrete operational, the preferred sequence puts the I phase last. This seemed to indicate the students need considerable amount of review of the concept before the invention takes place. In contrast, formal operational students prefer the invention to come first. It's as if the G phase of the learning cycle has already taken place, albeit some time earlier. If the concept is a brand new one, the sequences where the invention phase come after an introduction and before an expansion phase are the preferred ones. As far as students attitudes are concerned, they prefer sequences where the invention comes later in the sequence, although whether it should come second or last is not clear.

Selected quotations from the written BAR comments illustrate these and other points. It might be noted at this point, that all of the written comments from the BAR examinations were spontaneous and, although students were encouraged to write comments, there was no direction as to what the comments should say, other than they should be concerned with the lesson that was just completed.

In illustration of the idea that students do not like discussions and readings before laboratory work, one student said, "I did not like reading and lesson discussing lab being done before lab! If the concept was taught in a more straight forward manner, I am absolutely positive it would be better understood by everyone." To illustrate the disagreement over the GEI sequence consider the following students comments. The first student said, "There are definite problems with this sequence. The order was bad. We were asked questions that we could not answer and learned about them afterwards." In contrast, the second student said, "I thought the order of the activities was perfect." Other quotes about the same sequence also showed disagreement, "I think the order was mixed up. We should have discussed first and done the reading, then the laboratory demonstrations." In contrast, another student said, "I liked everything we did except I think I would have understood more if we would have had a discussion after the first lab, demonstration, reading, and then had another one after the end."

In a sequence where the invention phase comes first, a student said, "I basically understand the material; however, it is hard to understand what I am expected to know and what I will be tested over." Another student says, "The activity itself was easy enough, but I don't know what its purpose is." These comments, indicating a confusion about the purpose of the lesson, come even though the invention phase, where the concept to be learned was presented, is first. This is a sequence which is often recommended as desirable by some learning experts; we seriously question that position.

Interestingly enough, no comments concerning sequence were found in any of the control groups, where the theoretically ideal sequence was utilized.

Activities

There were several kinds of activities that were tested during the form variable discussed in Chapters 6, 8, and 10. However, in science, the most important activities usually are centered around the laboratory. This discussion will concern itself with the laboratory and the role that the laboratory plays in learning chemistry. In learning cycle formats, laboratory activities can be found most often in the gathering of the data phase. They can also be found in the expansion phase, although not necessarily so. The bulk of the form variable experiments indicates a very real need for laboratory activities especially for concrete operational students. This is, of course, consistent with a Piagetian analysis of the situation. Since concrete operational students depend upon an introduction to new concepts coming through concrete activity, it is natural to think that concrete operational students would be dependent upon laboratory activities rather than more abstract forms like reading or lecture to introduce a concept. Nevertheless, the instructor should be sure that it will be possible for students to obtain data which will allow the invention of the concept since it has been shown that laboratory materials that give ambiguous or unclear data tend to confuse rather than help students.

On balance, attitudes are favorable toward laboratory material. Table 12-1 summarizes the BAR written comments concerning laboratory in lessons where the laboratory was utilized. As can be seen from that table, 213 of the 466 total statements (46%) in those lessons are concerned with laboratory. Of these 213 comments an over-whelming number of them (95%) were positive. This is compared with a much smaller percent of positive comments on the lessons over all (66%). In summary, students spontaneously mention laboratory more often than any other format in their lessons and that their overall response is over-whelmingly positive.

Table 12-2 summarizes the BAR written comments where laboratory is not utilized. In this particular table 91 of the 207 comments (44%) were positive. When this number is contrasted with the percentage of positive comments in lessons where laboratory was utilized, it can be seen that the laboratory learning cycles

TABLE 12-1: BAR WRITTEN COMMENTS CONCERNING LABORATORY IN LESSONS WHERE LABORATORY WAS USED

LC#	Positive Lab	Negative Lab	Positive Total	Negative Total	Statements Concerning Lesson Formats
5	53	5	80	47	128
7	11	0	19	7	26
8	48	1	61	28	90*
10	22	1	31	12	43
12	43	3	85	47	132
14	26	0	30	17	47
TOTAL	203	10	306	153	466

*A Few Statements were judged to be neutral.

TABLE 12-2: BAR WRITTEN COMMENTS CONCERNING LABORATORY IN LESSONS WHERE LABORATORY WAS NOT USED

LC#	Positive Total	Negative Total	No Lab*	Statements Concerning Lesson Formats
7	20	22	14	56
8	16	16	1	33
10	31	25	19	75
14	24	13	6	43
TOTAL	91	76	40	207

*These statements were treated as a separate category.

were thought of in generally a more positive light than those that did not utilize laboratory. From Table 12-2 it can also be seen that 40 comments (19%) were comments indicating either that there was no laboratory and ought to be a laboratory, or that the laboratory itself was missed in this lesson. Although these statements were treated as a separate category in this table, they probably should be considered as negative comments. This is supported by some selected quotations from these written comments as follows: "I dislike this unit because I feel it would be easier for me if I had done the laboratory myself." "I also think a laboratory like the one presented in the idea reading that produced lead iodine would be helpful in demonstrating the chemical reaction, and it would make it easier to understand what takes place in the chemical reaction if we had actually done that laboratory." "I didn't really like any of this lesson because we didn't really have any laboratories, just information given to us. This didn't really help me because after a while you lost my attention, so I wasn't really listening."

There is some indication that students realize a need for the laboratory in conjunction with a discussion rather than by itself. For example, one student said, "I like doing the labs and then discussing what you have found and how you found it, as opposed to mid-high when they just made you do a lot of laboratories without ever discussing what you found or should have found. Sometimes I can do a lab and not be aware of what is really happening."

The laboratory is felt by some students to be primarily a motivator. For example, "I think it might be more interesting if you didn't go so long without a lab. Maybe we could stop our study for one or two days and do a laboratory that will teach us something on another subject. Then, we could come back and work on this subject refreshed and happy." Most students, however, feel that laboratory itself is an important learning tool. One student said, "The thing

I like best about this investigation is the laboratory that we did. I seem to be able to understand things more if I see how they work."

Language

Language has an important role in the invention phase of the learning cycle, especially with discussions which try and make sense out of G phase information. As such, language is used to develop a label and summary of the experiences gained in the gathering the data phase. From this point of view, language comes after experience and is used to identify or label it.

Language, however, can take other forms in a science lesson. For example, discussion/lecture can be used in place of other sorts of formats. Reading has traditionally been used as a substitute for other formats in science, also. The discussion of this section will concern itself with two aspects of language: Reading and Discussion/Lecture.

Reading. In the learning cycle, reading can be utilized a number of ways. Reading, for example, can be used to invent concepts and it can be used to review or to expand topics. The form experiments summarized in Chapters 6, 8, and 10, show that, with few exceptions, reading, is not an effective way of instructing students. The one exception concerns the learning associated with Learning Cycle 7 with formal operational students. It also seems that reading from an attitudental point of view, is not well thought of by either formal or concrete students. Table 12-3 summarizes the written comments concerning reading in the BAR written comments. Of the 70 comments concerning reading, only 12 (17%) were positive. In summary, students do not like reading in chemistry learning cycles, and furthermore, they do not seem to be very good at it. The technical material associated with reading chemistry may be different than other types of reading that may be found in other lessons. As a consequence, one should hesitate to say that reading, per se, is not an effective instructional

TABLE 12-3: BAR WRITTEN COMMENTS CONCERNING

READING AND DISCUSSION/LECTURE

	Positive Reading	Negative Reading	Positive Discussion/Lecture	Negative Discussion/Lecture
Multiple Format	7	45	61	33
Single Format	5	13	7	5
TOTAL	12	58	68	38

method. Also, there is some indication that formal students can learn from reading materials. This is no surprise from a Piagetian point of view. The abstract nature of developing concepts and information from reading is well within the ability of the students who are formal operational.

Concerning a "lesson control" form experiment where a reading format is used one student said, "This unit is too slow moving and too heavy. I find myself feeling like I am wading through jello." From another reading format experiment, "I hate doing the readings and no laboratory work."

Discussion/Lecture. The discussion format, especially associated with the invention phase of the learning cycle, but also found in expansion activities, has been shown in Chapters 4, 5, 7, and 9 to be a necessary part of the learning cycle. Its value seems not to stand on its own so much as to be used in combination with other phases; especially as a way of discussing data that were collected through laboratory activities. Although, not as popular as the laboratory, the discussion/lecture form is nevertheless basically thought of by the student as a positive influence on learning. Table 12-3 summarizes written comments concerning the discussion/lecture form. 68 of the 106 total comments (64%) concerning the discussion/lecture were positive. Student comments reflect the feeling that the discussion form is an important part of their learning. For example, one student said, "I like the labs the best, and I like the lectures the least; although, that is where I learn the most." Although this student mentions lectures, in fact, this lesson was taken from a control group and the information was discussed. Students very often don't mention or don't realize the distinction between lecture and discussion. Some, however, indicate a preference for discussion over lecture, as, for instance, the following: "I like the discussion because I understand a little more when we talk about it--I hate it just sitting here taking notes. I lost interest very quickly. Also, I didn't understand." This is from a lesson controlled format where the teacher lectured about rather than discussed information.

For further illustration of the role of the discussion taking part in a combination with other parts of the learning cycle, one student indicates: "I like best the class discussion, because it tied together the laboratory and questions and also gave me a chance to ask any unanswered questions about the laboratory or the discussion taking place." This is further illustrated by a quote which was used earlier and is repeated here: "I like doing the labs and then discussing what you have found and how you found it, as opposed to mid high school when they just made you do a lot of laboratories without ever discussing what you found or should have found. Sometimes I can do a lab and not be aware of what is really happening." When the invention discussions are missing, students notice it. This quote, for example, is typical of the student in a necessity experiment when there was no invention phase: "I think that we should spend more time on class discussion after the labs to make sure everything was understood."

Summary

In summary, the sequence of an activity seems to be important. There is some justification for the learning cycle in a GIE sequence. This supports the assimilation-accommodation-organization model that was developed in Chapter 1.

Laboratory as an instructional format for the learning cycle is effective and is highly thought of by students. It is especially important in view of the lack of emphasis on laboratory that seems to have evolved in the wake of recent emphasis on educational economy. There are two precautions concerning the use of laboratory in learning cycles. First of all, the laboratory should provide relatively clear and concrete data. Without it, the laboratory activity seems to do more harm than good. And secondly, the laboratory should be used in conjunction with discussion. Students need a chance to discuss their observations and results.

Teachers utilizing reading with learning cycles shouldn't expect them to be effective. Students don't like to read and they don't think reading is effective as an instructional format. Also they think reading is boring. Furthermore, concrete operational students don't seem to learn very well from reading materials. Perhaps more time should be devoted to helping students draw information from technical reading within the confines of the chemistry class. At any rate, teachers utilizing reading materials in the E phase of learning cycles should expect to extensively discuss the reading materials.

SEQUENCING LANGUAGE AND ACTIVITES
IN TEACHING
HIGH SCHOOL CHEMISTRY

A REPORT TO THE NATIONAL
SCIENCE FOUNDATION

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Appendices 1A through 10D

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Appendix 2A

Birnie-Abraham-Renner Quick Attitude Differential used by the Chemistry group in LC-5 through LC-14

INVESTIGATION 5

NAME ______________________
SECTION ______________________
DATE ______________________

For the last few days you have been studying a topic in Chemistry concerned with compounds. As part of the research study we are doing, we have been varying the teaching approach used in the Chemistry classes in an attempt to determine which is the best approach. We are very interested in student reaction to the approach used in your class.

Below you will find a line divided into seven parts with a word at the end of each line. Mark an x in the space which best describes how you feel at this time. On the back of this sheet write what you liked best and what you liked least about this activity.

SAMPLE: You feel very happy; the x is near the happy end of the scale.

unhappy	1	2	3	4	5	6	x 7	happy

Please tell us how you are reacting at the present time to what is taking place in your chemistry class.

1.	displeased	1	2	3	4	5	6	7	pleased
2.	dissatisfied	1	2	3	4	5	6	7	satisfied
3.	confused	1	2	3	4	5	6	7	not confused
4.	unenthusiastic	1	2	3	4	5	6	7	enthusiastic
5.	work is difficult	1	2	3	4	5	6	7	work is easy
6.	I am learning nothing new	1	2	3	4	5	6	7	everything is new to me
7.	we are moving too slowly	1	2	3	4	5	6	7	we are moving too quickly
8.	I dislike this topic	1	2	3	4	5	6	7	I like this topic
9.	I don't understand the words used	1	2	3	4	5	6	7	I understand the words used
10.	I can't solve the problems	1	2	3	4	5	6	7	I am able to solve the problems
11.	class activities seem mixed up	1	2	3	4	5	6	7	class activities seem in order
12.	I have unanswered questions	1	2	3	4	5	6	7	I understand the topic

INVESTIGATION 7

SECTION ____________

6

DATE ____________

For the last few days you have been studying a topic in Chemistry concerned with chemical reactions. As part of the research study we are doing, we have been varying the teaching approach used in the Chemistry classes in an attempt to determine which is the best approach. We are very interested in student reaction to the approach used in your class.

Below you will find a line divided into seven parts with a word at the end of each line. Mark an x in the space which best describes how you feel about this investigation. On the back of this sheet write what you liked best and what you liked least about this activity.

SAMPLE: You feel very happy; the x is near the happy end of the scale.

unhappy	1	2	3	4	5	6	x 7	happy

Please tell us how you are reacting at the present time to what is taking place in your chemistry class.

1.	displeased	1	2	3	4	5	6	7	pleased
2.	dissatisfied	1	2	3	4	5	6	7	satisfied
3.	confused	1	2	3	4	5	6	7	not confused
4.	unenthusiastic	1	2	3	4	5	6	7	enthusiastic
5.	work is difficult	1	2	3	4	5	6	7	work is easy
6.	I am learning nothing new	1	2	3	4	5	6	7	everything is new to me
7.	we are moving too slowly	1	2	3	4	5	6	7	we are moving too quickly
8.	I dislike this topic	1	2	3	4	5	6	7	I like this topic
9.	I don't understand the words used	1	2	3	4	5	6	7	I understand the words used
10.	I can't answer the questions	1	2	3	4	5	6	7	I am able to answer the questions
11.	class activities seem mixed up	1	2	3	4	5	6	7	class activities seem in order
12.	I have unanswered questions	1	2	3	4	5	6	7	I understand the topic
13.	This topic was taught in a boring way	1	2	3	4	5	6	7	This topic was taught in an interesting way

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INVESTIGATION 8

SECTION ____________________

DATE ____________________

For the last few days you have been studying a topic in Chemistry concerned with chemical reactions. As part of the research study we are doing, we have been varying the teaching approach used in the Chemistry classes in an attempt to determine which is the best approach. We are very interested in student reaction to the approach used in your class.

Below you will find a line divided into seven parts with a word at the end of each line. Mark an x in the space which best describes how you feel about this investigation. On the back of this sheet write what you liked best and what you liked least about this activity.

SAMPLE: You feel very happy; the x is near the happy end of the scale.

unhappy 1 2 3 4 5 6 x 7 happy

Please tell us how you are reacting at the present time to what is taking place in your chemistry class.

1. displeased 1 2 3 4 5 6 7 pleased

2. dissatisfied 1 2 3 4 5 6 7 satisfied

3. confused 1 2 3 4 5 6 7 not confused

4. unenthusiastic 1 2 3 4 5 6 7 enthusiastic

5. work is difficult 1 2 3 4 5 6 7 work is easy

6. I am learning nothing new 1 2 3 4 5 6 7 everything is new to me

7. we are moving too slowly 1 2 3 4 5 6 7 we are moving too quickly

8. I dislike this topic 1 2 3 4 5 6 7 I like this topic

9. I don't understand the words used 1 2 3 4 5 6 7 I understand the words used

10. I can't answer the questions 1 2 3 4 5 6 7 I am able to answer the questions

11. class activities seem mixed up 1 2 3 4 5 6 7 class activities seem in order

12. I have unanswered questions 1 2 3 4 5 6 7 I understand the topic

13. This topic was taught in a boring way 1 2 3 4 5 6 7 This topic was taught in an interesting way

INVESTIGATION 10

SECTION ____________

DATE ____________

For the last few days you have been studying a topic in Chemistry concerned with catalysts. As part of the research study we are doing, we have been varying the teaching approach used in the Chemistry classes in an attempt to determine which is the best approach. We are very interested in student reaction to the approach used in your class.

Below you will find a line divided into seven parts with a word at the end of each line. Mark an x in the space which best describes how you feel about this investigation. On the back of this sheet write what you liked best and what you liked least about this activity.

SAMPLE: You feel very happy; the x is near the happy end of the scale.

							x	
unhappy	1	2	3	4	5	6	7	happy

Please tell us how you are reacting at the present time to what is taking place in your chemistry class.

1.	displeased	1	2	3	4	5	6	7	pleased
2.	dissatisfied	1	2	3	4	5	6	7	satisfied
3.	confused	1	2	3	4	5	6	7	not confused
4.	unenthusiastic	1	2	3	4	5	6	7	enthusiastic
5.	work is difficult	1	2	3	4	5	6	7	work is easy
6.	I am learning nothing new	1	2	3	4	5	6	7	everything is new to me
7.	we are moving too slowly	1	2	3	4	5	6	7	we are moving too quickly
8.	I dislike this topic	1	2	3	4	5	6	7	I like this topic
9.	I don't understand the words used	1	2	3	4	5	6	7	I understand the words used
10.	I can't answer the questions	1	2	3	4	5	6	7	I am able to answer the questions
11.	class activities seem mixed up	1	2	3	4	5	6	7	class activities seem in order
12.	I have unanswered questions	1	2	3	4	5	6	7	I understand the topic
13.	This topic was taught in a boring way	1	2	3	4	5	6	7	This topic was taught in an interesting way

INVESTIGATION 12

Section ____________

Date __________

For the last few days you have been studying a topic in Chemistry concerned with heat. As part of the research study we are doing, we have been varying the teaching approach used in the Chemistry classes in an attempt to determine which is the best approach. We are very interested in student reaction to the approach used in your class.

SAMPLE

Below you will find seven numbers between two words or phrases. You are requested to circle the number which best describes how you feel at this time. For example, if you felt very relaxed you might circle number 2.

relaxed 1 [✓ 2] 3 4 5 6 7 tense

Please tell us your reaction to the investigation you have just completed by circling the appropriate number.

1.	displeased	1	2	3	4	5	6	7	pleased
2.	dissatisfied	1	2	3	4	5	6	7	satisfied
3.	confused	1	2	3	4	5	6	7	not confused
4.	unenthusiastic	1	2	3	4	5	6	7	enthusiastic
5.	work is difficult	1	2	3	4	5	6	7	work is easy
6.	class activities seem mixed up	1	2	3	4	5	6	7	class activities seem in order
7.	I have unanswered questions	1	2	3	4	5	6	7	I understand the topic
8.	I dislike this topic	1	2	3	4	5	6	7	I like this topic
9.	I don't understand the words used	1	2	3	4	5	6	7	I understand the words used
10.	I can't solve the problems	1	2	3	4	5	6	7	I am able to solve the problems
11.	everything is new to me	1	2	3	4	5	6	7	I am learning nothing new
12.	we are moving too quickly	1	2	3	4	5	6	7	we are moving too slowly

On the back of this sheet write what you liked best and what you liked least about this activity.

INVESTIGATION 14

Section ___________

Date ___________

For the last few days you have been studying a topic in Chemistry concerned with acids and bases. As part of the research study we are doing, we have been varying the teaching approach used in the Chemistry classes in an attempt to determine which is the best approach. We are very interested in student reaction to the approach used in your class.

SAMPLE

Below you will find seven numbers between two words or phases. You are requested to circle the number which best describes how you feel at this time. For example, if you felt very relaxed you might circle number 2

relaxed 1 [✓ 2] 3 4 5 6 7 tense

Please tell us your reaction to the investigation you have just completed by circling the appropriate number.

1.	displeased	1	2	3	4	5	6	7	pleased
2.	dissatisfied	1	2	3	4	5	6	7	satisfied
3.	confused	1	2	3	4	5	6	7	not confused
4.	unenthusiastic	1	2	3	4	5	6	7	enthusiastic
5.	work is difficult	1	2	3	4	5	6	7	work is easy
6.	class activities seem mixed up	1	2	3	4	5	6	7	class activities seem in order
7.	I have unanswered questions	1	2	3	4	5	6	7	I understand the topic
8.	I dislike this topic	1	2	3	4	5	6	7	I like this topic
9.	I don't understand the words used	1	2	3	4	5	6	7	I understand the words used
10.	I can't solve the problems	1	2	3	4	5	6	7	I am able to solve the problems
11.	everything is new to me	1	2	3	4	5	6	7	I am learning nothing new
12.	we are moving too quickly	1	2	3	4	5	6	7	we are moving too slowly

On the back of this sheet write what you liked best and what you liked least about this activity

Appendix 2B

BAR Written Comments Form

BAR Written Comments

LC- ______ CLASS ______ N = ______, ______ with comments

	+	0	-	Comments
Lab				
Discussion				
Demo				
Questions				
Problems				
Readings				
Lecture				

	#	Comments
I'm Confused		
Activities Not Logical		
Too fast		
Too slow		
I Understand		
I Like		
I Don't Like		
Activities Are Logical		

Quotes:

APPENDIX 3A

Individual Student Characteristics

TABLE 1
STUDENT CHARACTERISTICS

------------------------ TEACHER=1 CLASS=11 ------------------------

ID	TEACHER	CLASS	SEX	AGE	IQ	GPA	GEFT	PRE PIAGET	POST PIAGET
1	1	1	F	16.0	.	2.00	.	.	.
2	1	1	F	15.9	114	3.50	13	4.0	5.0
3	1	1	F	16.2	121	4.00	11	5.0	.
4	1	1	M	16.3	.	1.25	12	.	5.5
5	1	1	M	16.5	117	4.00	18	6.0	.
6	1	1	F	16.3	103	3.75	10	4.0	4.5
7	1	1	M	16.0	102	2.00	12	3.5	4.0
8	1	1	M	17.1	100	1.25	7	4.5	4.5
9	1	1	F	16.7	114	3.00	9	4.5	5.0
10	1	1	M	17.6	106	2.75	16	5.0	.
11	1	1	F	15.9	119	3.00	18	5.0	5.5
12	1	1	M	16.7	125	4.00	14	4.5	5.5
13	1	1	M	18.0	92	1.50	11	3.0	.
14	1	1	M	17.7	111	3.75	15	6.0	6.0
15	1	1	M	16.5	122	3.75	11	5.0	5.5
16	1	1	M	16.4	89	4.00	.	5.0	5.5
17	1	1	M	16.3	.	2.75	.	.	5.0
18	1	1	M	16.4	108	2.50	16	4.5	6.0
19	1	1	F	16.8	95	2.25	2	2.5	3.0
501	1	1	M	16.0	.	1.50	.	.	4.0
502	1	1	M	16.5	124	4.00	16	5.5	6.0
503	1	1	F	16.9	.	4.00	.	.	4.0
504	1	1	F	16.6	.	1.00	.	.	5.0
505	1	1	M	16.3	.	4.00	.	.	.
506	1	1	M	15.5	.	2.75	.	.	.
507	1	1	M	15.7	.	3.50	.	.	5.0
509	1	1	M	15.9	118	3.50	14	5.5	5.5

TABLE 1
STUDENT CHARACTERISTICS

------------------------- TEACHER=1 CLASS=11 -------------------------

ID	TEACHER	CLASS	SEX	AGE	IQ	GPA	GEFT	PRE PIAGET	POST PIAGET
1	1	1	F	16.0	.	2.00	.	.	.
2	1	1	F	15.9	114	3.50	13	4.0	5.0
3	1	1	F	16.2	121	4.00	11	5.0	.
4	1	1	M	16.3	.	1.25	12	.	5.5
5	1	1	M	16.5	117	4.00	18	6.0	.
6	1	1	F	16.3	103	3.75	10	4.0	4.5
7	1	1	M	16.0	102	2.00	12	3.5	4.0
8	1	1	M	17.1	100	1.25	7	4.5	4.5
9	1	1	F	16.7	114	3.00	9	4.5	5.0
10	1	1	M	17.6	106	2.75	16	5.0	.
11	1	1	F	15.9	119	[illegible]	18	5.0	5.5
12	1	1	M	16.7	125	4.00	14	4.5	5.5
13	1	1	M	18.0	92	1.50	11	3.0	.
14	1	1	M	17.7	111	3.75	15	6.0	6.0
15	1	1	M	16.5	122	3.75	11	5.0	3.5
16	1	1	M	16.4	89	4.00	.	5.0	5.5
17	1	1	M	16.3	.	2.75	.	.	6.0
18	1	1	M	16.4	108	2.50	16	4.5	5.0
19	1	1	F	16.8	95	2.25	2	2.5	3.0
501	1	1	M	16.0	.	1.50	.	.	4.0
502	1	1	M	16.5	124	4.00	16	5.5	6.0
503	1	1	F	16.9	.	4.00	.	.	4.0
504	1	1	F	16.6	.	1.00	.	.	5.0
505	1	1	M	16.3	.	4.00	.	.	.
506	1	1	M	18.5	.	2.75	.	.	.
507	1	1	M	15.7	.	3.50	.	.	5.0
509	1	1	M	15.9	118	3.50	14	5.5	5.5

TABLE 1
STUDENT CHARACTERISTICS

-------------------------- TEACHER=1 CLASS=14 --------------------------

ID	TEACHER	CLASS	SEX	AGE	IQ	GPA	GEFT	PRE PIAGET	POST PIAGET
20	1	4	M	16.8	105	1.50	15	4.5	.
21	1	4	F	16.6	112	3.25	12	4.5	4.5
22	1	4	M	15.9	121	2.75	16	5.5	5.0
23	1	4	F	16.3	120	4.00	12	4.0	4.5
24	1	4	M	16.5	124	4.00	16	5.5	6.0
25	1	4	F	16.8	117	3.00	18	5.0	4.5
26	1	4	M	17.6	105	2.75	12	4.0	4.0
27	1	4	F	16.1	109	3.75	11	5.5	6.0
28	1	4	F	15.0	140	4.00	17	5.5	.
29	1	4	M	16.3	114	2.75	18	5.5	5.5
30	1	4	M	16.9	97	2.00	16	4.0	5.0
31	1	4	M	17.3	108	3.25	8	4.5	5.0
32	1	4	F	16.7	107	2.75	8	4.0	4.5
33	1	4	M	16.8	135	4.00	15	5.0	5.5
34	1	4	M	16.4	133	3.75	18	5.5	.
35	1	4	F	15.8	91	2.00	6	3.0	3.5
36	1	4	F	15.9	118	4.00	17	4.5	.
37	1	4	M	16.3	129	4.00	9	5.5	5.5
508	1	4	M	16.2	111	1.50	17	5.0	5.5
510	1	4	M	16.2	.	3.00	.	.	5.0
518	1	4	M	16.0	102	1.00	12	3.5	4.0
519	1	4	M	16.8	.	.	.	.	.

TABLE 1
STUDENT CHARACTERISTICS

------------------------ TEACHER=1 CLASS=16 ------------------------

ID	TEACHER	CLASS	SEX	AGE	IQ	GPA	GEFT	PRE PIAGET	POST PIAGET
38	1	6	F	16.9	.	3.25	16	.	5.0
39	1	6	M	16.2	120	3.00	10	5.5	5.0
41	1	6	M	18.0	81	1.50	4	2.5	.
42	1	6	M	15.8	100	3.75	10	5.5	3.5
43	1	6	F	16.5	100	2.00	5	5.0	.
44	1	6	M	16.5	112	2.25	14	6.0	.
45	1	6	M	15.9	105	1.25	17	3.5	4.0
46	1	6	F	16.8	116	2.75	.	3.5	5.0
47	1	6	F	15.8	118	2.50	15	5.0	.
48	1	6	M	16.8	123	4.00	10	5.0	5.5
49	1	6	M	16.0	101	1.50	6	3.5	4.0
50	1	6	F	16.7	125	3.50	16	5.0	5.5
51	1	6	F	16.7	121	4.00	16	5.0	5.5
52	1	6	F	16.3	106	3.00	.	.	4.5
53	1	6	F	15.8	124	4.00	15	5.5	.
54	1	6	F	16.1	119	3.00	13	5.0	5.0
55	1	6	F	15.8	137	3.00	.	.	4.5
56	1	6	F	16.3	103	1.75	12	.	4.0
57	1	6	F	16.0	117	3.50	11	4.0	.
58	1	6	F	17.0	95	1.75	5	3.0	3.0
59	1	6	M	16.1	114	3.00	4	5.0	5.0
60	1	6	F	16.0	122	3.25	10	4.5	4.5
61	1	6	M	16.8	131	4.00	17	5.0	5.0
62	1	6	F	16.0	136	4.00	16	5.0	5.5
440	1	6	M	15.9	150	4.00	18	6.0	6.0
511	1	6	F	16.7	.	4.00	.	.	.
512	1	6	M	16.0	.	1.00	.	.	5.0
513	1	6	M	15.8	91	0.50	6	3.0	3.5
520	1	6	F	16.1	.	.	.	.	.

TABLE 1
STUDENT CHARACTERISTICS

------------------------- TEACHER=2 CLASS=21 -------------------------

ID	TEACHER	CLASS	SEX	AGE	IQ	GPA	GEFT	PRE PIAGET	POST PIAGET
63	2	1	M	16.2	111	2.50	17	5.0	5.5
64	2	1	F	16.3	135	4.00	18	4.5	5.5
65	2	1	F	15.9	103	1.75	9	4.0	.
66	2	1	F	17.0	103	2.50	11	3.0	.
67	2	1	M	17.2	103	1.25	18	4.0	4.0
68	2	1	M	17.3	113	2.00	13	4.0	.
69	2	1	F	16.5	120	4.00	18	5.0	5.5
70	2	1	F	16.4	106	2.25	13	.	4.5
71	2	1	M	17.4	104	1.50	14	4.0	.
72	2	1	F	16.2	118	3.75	16	4.5	5.5
73	2	1	M	16.5	122	4.00	12	5.0	6.0
74	2	1	F	16.8	123	4.00	13	6.0	6.0
75	2	1	F	16.5	126	4.00	16	6.0	6.0
76	2	1	F	15.8	127	4.00	18	5.0	6.0
77	2	1	F	16.5	116	4.00	17	5.5	5.5
78	2	1	F	17.3	90	1.25	4	.	4.0
79	2	1	F	16.9	91	0.75	14	4.5	.
80	2	1	F	18.5	92	1.75	13	3.5	.
81	2	1	M	16.4	134	3.50	12	.	.
82	2	1	M	16.2	136	4.00	14	5.5	5.5
83	2	1	F	17.6	88	1.25	16	5.5	5.5
84	2	1	M	16.7	.	3.00	9	6.0	6.0
85	2	1	F	16.3	107	4.00	16	5.0	5.0
86	2	1	M	16.9	133	4.00	13	.	5.5
514	2	1	M	16.3	118	1.50	5	5.0	5.0
515	2	1	F	16.0	120	4.00	14	5.5	5.0
516	2	1	F	16.1	.	1.00	.	.	3.5
517	2	1	M	16.1	.	4.00	.	.	6.0
521	2	1	F	15.8	130	.	.	5.5	.
522	2	1	F	16.0	112	.	4	4.0	.

TABLE 1
STUDENT CHARACTERISTICS

------------------------- TEACHER=2   CLASS=22 --------------------------

ID	TEACHER	CLASS	SEX	AGE	IQ	GPA	GEFT	PRE PIAGET	POST PIAGET
87	2	2	F	17.4	100	3.00	10	4.5	4.5
88	2	2	M	16.3	118	2.50	5	5.0	5.0
89	2	2	F	16.0	120	3.50	14	5.5	5.0
90	2	2	F	16.2	118	1.75	17	5.0	4.5
91	2	2	M	16.0	118	3.00	10	5.5	6.0
92	2	2	F	17.6	112	3.25	6	5.0	.
93	2	2	F	17.0	108	2.00	14	.	5.5
94	2	2	M	16.8	109	2.00	14	4.5	4.0
95	2	2	F	16.1	127	3.75	15	5.0	5.0
96	2	2	M	16.4	101	2.50	17	.	6.0
97	2	2	F	16.9	103	2.75	.	3.5	5.0
98	2	2	F	16.3	121	4.00	16	.	6.0
99	2	2	M	16.7	125	3.00	11	4.5	.
100	2	2	M	16.3	106	2.00	17	2.5	5.5
101	2	2	M	16.1	130	3.50	18	4.5	5.5
102	2	2	F	16.6	120	4.00	11	4.5	4.5
103	2	2	F	16.0	112	3.00	4	4.0	.
104	2	2	F	17.7	110	2.75	14	4.0	5.0
105	2	2	M	17.0	121	2.50	17	5.0	.
106	2	2	M	15.9	.	3.50	.	.	4.5
107	2	2	F	17.0	97	3.00	9	3.5	4.0
108	2	2	M	16.5	103	2.75	11	3.5	4.5
109	2	2	M	17.6	120	2.75	.	.	6.0
110	2	2	M	16.6	109	3.00	14	5.0	5.5
111	2	2	M	.	124	3.50	17	6.0	5.0

TABLE 1
STUDENT CHARACTERISTICS

------------------------- TEACHER=2 CLASS=25 -------------------------

ID	TEACHER	CLASS	SEX	AGE	IQ	GPA	GEFT	PRE PIAGET	POST PIAGET
112	2	5	M	16.5	102	1.25	7	3.0	.
113	2	5	M	16.7	97	0.50	9	4.0	4.0
114	2	5	F	16.0	77	1.00	10	2.5	.
115	2	5	F	16.3	103	1.25	11	.	3.0
116	2	5	F	17.7	102	2.25	12	3.5	4.5
117	2	5	M	16.3	107	3.00	10	4.0	4.0
118	2	5	F	16.8	108	3.50	16	5.3	4.5
119	2	5	M	16.2	119	1.75	7	.	.
120	2	5	F	16.1	118	2.50	11	5.5	.
121	2	5	M	15.9	107	1.75	6	4.0	3.0
122	2	5	M	18.3	92	1.50	9	4.0	.
123	2	5	F	15.9	115	3.75	16	4.5	5.5
124	2	5	M	16.0	104	3.50	2	5.0	5.0
125	2	5	F	16.3	98	2.00	6	.	3.5
126	2	5	F	16.3	125	3.50	16	.	5.0
127	2	5	M	16.4	131	2.75	15	6.0	5.5
128	2	5	F	16.3	143	4.00	15	6.0	6.0
129	2	5	F	17.0	102	1.75	10	3.5	4.0
130	2	5	F	15.9	102	2.25	10	4.5	.
131	2	5	F	16.8	108	2.00	12	.	.
132	2	5	F	16.4	108	4.00	4	3.5	4.0
133	2	5	F	16.1	.	2.50	16	3.5	.
134	2	5	M	16.3	116	2.50	17	5.3	.
135	2	5	M	16.6	100	2.25	4	3.5	3.5
136	2	5	M	16.7	.	3.00	15	5.5	5.5
137	2	5	F	16.3	112	3.50	11	5.0	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS

-------------- TEACHER=1 CLASS=11------------------------

ID	L.C.2 CAT 1	L.C.2 CAT 2	L.C.2 CAT 3	L.C.2 CAT 4	L.C.5 CAT 1	L.C.5 CAT 2
1	33	62	33	76	0	67
2	57	57	38	76	33	78
3	57	57	43	67	33	99
4	52	52	43	.	33	56
5	62	76	57	67	33	99
6	38	57	43	67	33	78
7	48	43	38	52	0	33
8	52	52	52	62	33	11
9	43	52	33	62	33	56
10	33	48	62	76	33	89
11	48	67	33	43	67	89
12	62	57	29	90	0	89
13	38	33	.	57	33	22
14	52	67	52	76	33	99
15	48	67	48	52	33	56
16	0	67	.	57	33	78
17	57	52	38	.	33	78
18	43	43	33	57	33	99
19	38	62	48	48	33	78
501	.	.	.	.	.	.
502	.	.	.	.	.	.
503	.	.	.	.	.	.
504	.	.	.	.	.	.
505	.	.	.	.	.	.
506	43	67	43	81	33	56
507	.	.	.	.	.	89
509	52	52	43	71	33	78

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES TWO, FIVE AND SEVEN

-------------------- TEACHER=1 CLASS= 11--------------------------

ID	L.C.2 CAT 1	L.C.2 CAT 2	L.C.2 CAT 3	L.C.2 CAT 4	L.C.5 CAT 1	L.C.5 CAT 2	L.C.7 CAT 1	L.C.7 CAT 2	L.C.7 CAT 3
1	33	62	33	76	0	67	33	61	95
2	57	57	38	76	33	78	33	76	86
3	57	57	43	67	33	99	.	90	81
4	52	52	43	.	33	56	.	67	67
5	62	76	57	67	33	99	33	86	.
6	38	57	43	67	33	78	33	95	.
7	48	43	38	52	0	33	33	57	.
8	52	52	52	62	33	11	0	86	67
9	43	52	33	62	33	56	33	48	81
10	33	48	62	76	33	89	33	81	71
11	48	67	33	43	67	89	33	61	81
12	62	57	29	90	0	89	33	86	76
13	38	33	.	57	33	22	33	71	.
14	52	67	52	76	33	99	33	71	81
15	48	67	48	52	33	56	.	61	52
16	0	67	.	57	33	78	33	95	95
17	57	52	38	.	33	78	0	86	76
18	43	43	33	57	33	99	33	86	81
19	38	62	48	48	33	78	33	52	71
501	.	.	.	.	.	.	.	.	43
502	.	.	.	.	.	.	.	.	86
503	.	.	.	.	.	.	.	.	86
504	.	.	.	.	.	.	.	.	71
505	.	.	.	.	.	.	.	.	81
506	43	67	43	81	33	56	33	81	76
507	.	.	.	.	.	89	.	90	76
509	52	52	43	71	33	78	0	86	86

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES TWO, FIVE AND SEVEN

------------------- TEACHER=1 CLASS=14 -------------------------

ID	L.C.2 CAT 1	L.C.2 CAT 2	L.C.2 CAT 3	L.C.2 CAT 4	L.C.5 CAT 1	L.C.5 CAT 2	L.C.7 CAT 1	L.C.7 CAT 2	L.C.7 CAT 3
20	67	57	52	57	67	11	33	62	.
21	52	62	43	43	33	67	67	67	76
22	57	71	67	67	33	78	0	95	95
23	48	38	43	.	0	56	33	81	86
24	67	57	57	71	67	99	67	76	.
25	33	.	33	57	33	33	33	67	81
26	62	62	33	67	33	22	0	.	61
27	62	52	33	62	33	99	33	67	67
28	90	67	86	90	33	99	67	76	.
29	62	38	57	67	33	56	67	90	95
30	33	43	48	43	33	56	0	43	67
31	62	52	29	81	33	44	0	.	.
32	48	48	33	.	33	56	33	81	90
33	52	52	48	48	99	33	33	86	86
34	90	71	67	67	33	78	33	86	86
35	38	10	5	52	33	.	.	.	.
36	29	52	57	81	.	78	33	67	76
37	57	43	57	71	99	99	33	95	86
508	.	.	.	.	.	.	.	.	71
510	.	.	.	.	.	.	.	.	71
518	.	.	.	.	.	.	.	.	61
519	.	.	.	.	.	.	.	.	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES TWO, FIVE AND SEVEN

-------------------- TEACHER=1   CLASS= 16-----------------------

ID	L.C.2 CAT 1	L.C.2 CAT 2	L.C.2 CAT 3	L.C.2 CAT 4	L.C.5 CAT 1	L.C.5 CAT 2	L.C.7 CAT 1	L.C.7 CAT 2	L.C.7 CAT 3
38	67	48	43	62	.	89	33	.	95
39	57	62	57	57	33	78	0	48	95
41	5	14	10	33	33	33	33	71	.
42	33	76	71	81	33	78	33	76	90
43	24	33	24	.	0	56	0	62	86
44	52	62	.	67	33	78	0	76	81
45	43	33	62	48	33	78	33	81	76
46	48	52	33	67	33	99	33	61	67
47	62	57	43	71	33	78	0	43	67
48	43	52	62	67	99	78	33	76	81
49	43	14	.	43	33	33	33	61	61
50	48	29	67	71	33	99	33	76	71
51	38	62	81	71	67	.	33	95	95
52	5	48	38	48	33	89	33	57	76
53	48	48	67	67	67	99	33	81	.
54	57	57	52	67	33	99	33	76	.
55	62	52	67	67	67	99	.	86	.
56	33	.	.	24	33	56	33	81	71
57	48	48	33	52	33	78	33	81	71
58	19	33	29	52	0	56	33	71	81
59	43	67	71	81	33	56	33	86	95
60	57	67	71	71	0	99	33	76	57
61	67	86	71	90	33	99	33	76	95
62	67	67	67	81	33	99	33	57	.
440	38	90	43	62	33	78	33	76	95
511	.	.	.	.	.	.	.	.	67
512	.	.	.	.	.	.	.	.	90
513	.	.	.	.	.	.	.	.	57
520	43	48	43	52	.	.	.	.	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES TWO, FIVE AND SEVEN

-------------------- TEACHER=2   CLASS= 21--------------------------

ID	L.C.2 CAT 1	L.C.2 CAT 2	L.C.2 CAT 3	L.C.2 CAT 4	L.C.5 CAT 1	L.C.5 CAT 2	L.C.7 CAT 1	L.C.7 CAT 2	L.C.7 CAT 3
63	48	48	33	62	33	.	33	57	95
64	52	57	43	.	99	.	33	86	.
65	57	52	33	57	33	.	33	43	.
66	48	33	62	52	33	.	.	52	67
67	29	57	38	71	33	.	33	62	81
68	57	71	71	71	33	.	33	62	61
69	67	67	76	81	99	.	67	86	86
70	.	43	43	48	33	.	33	62	52
71	48	43	33	.	67	.	33	62	71
72	57	52	33	52	33	.	0	86	86
73	43	33	52	81	67	.	33	86	76
74	62	67	33	43	33	.	33	95	95
75	43	48	62	81	33	.	33	86	.
76	57	71	76	86	99	.	33	76	95
77	52	48	33	52	99	.	67	95	76
78	14	33	43	43	33	.	33	57	71
79	48	48	62	57	33	.	99	81	.
80	33	52	29	43	.	.	67	33	43
81	62	.	.	71	99	.	.	95	76
82	52	76	90	99	99	.	67	95	86
83	33	48	48	57	33	.	0	76	81
84	62	62	57	.	33	.	33	81	.
85	48	67	71	62	33	.	67	95	95
86	76	57	.	67	67	.	33	90	86
514	.	.	.	.	.	.	.	.	86
515	.	.	.	.	.	.	.	.	86
516	.	.	.	.	.	.	.	.	81
517	.	.	.	.	.	.	.	.	.
521	57	57	43	76	.	.	.	.	.
522	.	.	.	.	.	.	.	.	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLE TWELVE

------------- TEACHER=1   CLASS=11--------------------

ID	L.C.12 CAT 1	L.C.12 CAT 2	LC12 CAT 3	L.C.12 CAT 4	L.C.12 CAT 5
1	44	26.16	51.14	.	67
2	56	82.16	62.14	56	67
3	44	48.16	51.14	67	67
4	.	37.16	51.14	56	.
5	.	.	.	.	.
6	33	37.16	39.14	56	56
7	.	.	.	.	.
8	33	60.16	.	89	67
9	56	60.16	51.14	67	67
10	56	60.16	39.14	67	67
11	.	.	28.14	78	78
12	56	60.16	.	78	89
13	.	.	.	.	.
14	89	48.16	51.14	67	67
15	56	82.16	.	67	78
16	78	60.16	51.14	78	67
17	99	82.16	62.14	78	89
18	56	71.16	51.14	67	78
19	22	48.16	39.14	44	56
501	44	60.16	51.14	44	67
502	99	93.16	.	89	89
503	56	.	73.14	78	78
504	33	.	28.14	44	56
505	67	71.16	.	56	89
506	.	82.16	62.14	78	89
507	99	82.16	51.14	78	78
509	67	71.16	73.14	56	67

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES TWO, FIVE AND SEVEN

---------------------- TEACHER=2   CLASS=22 ----------------------

ID	L.C.2 CAT 1	L.C.2 CAT 2	L.C.2 CAT 3	L.C.2 CAT 4	L.C.5 CAT 1	L.C.5 CAT 2	L.C.7 CAT 1	L.C.7 CAT 2	L.C.7 CAT 3
87	67	52	52	57	0	44	0	57	81
88	43	62	33	38	33	56	.	52	.
89	43	.	38	33	33	99	0	86	.
90	19	62	5	62	0	22	0	62	86
91	62	52	.	52	33	78	33	86	81
92	62	67	48	52	33	.	33	86	76
93	.	52	33	33	33	22	0	81	67
94	57	52	43	43	33	67	33	86	61
95	57	52	38	57	33	78	0	63	71
96	48	62	38	52	33	67	33	76	67
97	57	62	52	52	33	78	0	76	76
98	71	.	52	67	99	67	33	81	95
99	62	48	43	57	33	44	33	57	67
100	48	57	33	62	33	56	33	95	.
101	86	52	67	76	33	67	33	71	76
102	.	62	48	57	33	56	0	86	86
103	76	71	38	52	33	33	33	81	81
104	33	48	.	43	33	56	0	71	31
105	71	52	52	.	33	56	33	71	81
106	.	.	.	.	.	.	33	95	95
107	57	52	38	43	33	33	67	81	76
108	48	48	38	38	33	99	33	91	86
109	48	67	71	76	33	56	33	.	95
110	67	48	48	62	33	99	0	62	52
111	76	76	38	99	67	78	33	91	76

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES TWO, FIVE AND SEVEN

---------------------- TEACHER=2 CLASS=25 ----------------------------

ID	L.C.2 CAT 1	L.C.2 CAT 2	L.C.2 CAT 3	L.C.2 CAT 4	L.C.5 CAT 1	L.C.5 CAT 2	L.C.7 CAT 1	L.C.7 CAT 2	L.C.7 CAT 3
112	.	52	43	.	33	67	33	52	76
113	14	43	48	62	33	56	0	62	76
114	43	33	33	48	67	33	33	48	.
115	48	57	38	29	33	56	33	57	[illegible]
116	48	57	48	48	33	56	33	76	86
117	38	76	48	76	.	22	67	71	81
118	48	62	48	71	33	89	33	76	.
119	76	52	62	67	33	56	0	86	81
120	48	57	33	52	33	89	67	76	86
121	52	48	29	48	33	44	33	76	71
122	48	48	43	48	33	33	33	52	.
123	.	62	52	.	67	78	67	95	86
124	57	62	67	67	0	78	33	76	81
125	.	.	38	19	33	67	.	67	14
126	67	71	33	90	67	99	.	95	90
127	76	67	57	81	33	89	67	86	86
128	71	81	67	62	67	78	67	86	86
129	52	38	38	33	33	33	33	71	71
130	62	43	38	48	33	67	.	76	67
131	.	38	33	33	33	33	33	67	76
132	43	71	43	48	33	78	33	71	71
133	67	57	43	57	33	67	33	71	76
134	57	76	67	71	33	99	33	90	90
135	57	52	48	52	33	78	33	86	48
136	71	71	67	95	33	89	67	86	86
137	52	62	43	71	33	99	0	86	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLE TWELVE

------------ TEACHER=1 CLASS= 14------------------

ID	L.C.12 CAT 1	L.C.12 CAT 2	LC12 CAT 3	L.C.12 CAT 4	L.C.12 CAT 5
20	.	.	.	.	.
21	44	37.16	84.14	89	89
22	67	71.16	84.14	89	89
23	67	60.16	84.14	78	89
24	.	.	.	.	.
25	44	60.16	62.14	44	56
26	.	15.16	62.14	.	.
27	56	93.16	84.14	89	78
28	.	.	.	.	.
29	56	60.16	51.14	56	78
30	78	48.16	73.14	67	67
31	56	60.16	.	.	.
32	22	48.16	.	67	78
33	67	71.16	94.14	89	89
34	56	37.16	62.14	56	89
35	.	.	.	.	.
36	99	60.16	62.14	.	89
37	78	82.16	62.14	89	89
508	22	48.16	51.14	67	67
510	56	37.16	51.14	67	78
518	0	4.16	6.14	22	22
519	.	.	.	.	.

3A-1[illegible]

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLE TWELVE

------------- TEACHER=1 CLASS= 16-------------------

ID	L.C.12 CAT 1	L.C.12 CAT 2	LC12 CAT 3	L.C.12 CAT 4	L.C.12 CAT 5
38	99	60.16	73.14	89	67
39	56	48.16	73.14	67	78
41	.	.	.	.	.
42	67	48.16	62.14	44	67
43	33	37.16	28.14	33	33
44	.	60.16	51.14	.	56
45	56	93.16	62.14	67	78
46	78	60.16	39.14	67	67
47	67	82.16	62.14	89	78
48	67	93.16	94.14	78	99
49	33	48.16	28.14	33	33
50	67	71.16	39.14	78	44
51	56	71.16	62.14	67	67
52	0	48.16	62.14	78	33
53	44	71.16	62.14	78	.
54	44	82.16	51.14	.	44
55	78	60.16	51.14	67	67
56	11	37.16	17.14	33	33
57	67	71.16	73.14	67	78
58	11	26.16	28.14	33	33
59	99	71.16	62.14	78	67
60	56	82.16	62.14	11	78
61	89	103.16	73.14	89	67
62	89	82.16	73.14	56	.
440	99	82.16	73.14	67	78
511	67	60.16	73.14	78	78
512	44	48.16	51.14	44	67
513	33	.	17.14	33	.
520	.	.	.	.	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLE TWELVE

------------- TEACHER=2 CLASS= 21-------------------

ID	L.C.12 CAT 1	L.C.12 CAT 2	LC12 CAT 3	L.C.12 CAT 4	L.C.12 CAT 5
63	.	.	.	.	.
64	56	.	.	67	67
65	.	71.16	73.14	78	78
66	.	.	.	.	.
67	78	37.16	51.14	56	56
68	.	71.16	62.14	78	.
69	67	93.16	94.14	99	99
70	44	48.16	51.14	67	67
71	56	71.16	51.14	56	78
72	78	71.16	51.14	56	67
73	56	82.16	84.14	89	78
74	89	71.16	62.14	78	67
75	89	93.16	94.14	.	99
76	67	82.16	84.14	89	89
77	78	82.16	84.14	78	89
78	56	48.16	.	67	67
79	.	.	28.14	.	.
80	33	.	73.14	67	.
81	78	.	73.14	89	89
82	56	71.16	84.14	89	89
83	.	37.16	39.14	67	67
84	.	60.16	84.14	56	67
85	78	82.16	84.14	78	89
86	56	93.16	62.14	89	78
514	67	71.16	.	.	78
515	56	93.16	73.14	89	78
516	67	48.16	51.14	.	33
517	67	60.16	.	89	99
521	.	.	.	.	.
522	.	.	.	.	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLE TWELVE

------------ TEACHER=2 CLASS= 22------------------

ID	L.C.12 CAT 1	L.C.12 CAT 2	LC12 CAT 3	L.C.12 CAT 4	L.C.12 CAT 5
87	.	48.16	.	44	33
88	.	.	.	.	.
89	.	.	.	.	.
90	.	4.16	62.14	56	67
91	78	60.16	62.14	78	56
92	33	48.16	62.14	67	44
93	78	48.16	62.14	56	56
94	56	93.16	73.14	78	78
95	78	71.16	.	67	67
96	56	.	94.14	89	67
97	44	4.16	62.14	33	56
98	67	93.16	51.14	89	89
99	56	71.16	.	78	67
100	67	.	94.14	89	89
101	78	82.16	.	89	67
102	11	48.16	51.14	67	56
103	.	.	.	.	.
104	22	60.16	62.14	78	67
105	33	60.16	.	67	56
106	67	82.16	73.14	78	78
107	33	71.16	.	56	56
108	33	26.16	51.14	44	44
109	89	103.16	73.14	89	89
110	33	60.16	51.14	56	67
111	67	.	.	78	89

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLE TWELVE

------------- TEACHER=2 CLASS=25 -------------------

ID	L.C.12 CAT 1	L.C.12 CAT 2	LC12 CAT 3	L.C.12 CAT 4	L.C.12 CAT 5
112	56	71.16	.	33	33
113	56	37.16	62.14	67	67
114	.	.	.	.	.
115	56	48.16	28.14	44	44
116	78	.	51.14	56	67
117	78	60.16	.	67	.
118	56	82.16	62.14	78	67
119	67	71.16	51.14	56	89
120	44	.	.	33	44
121	44	60.16	.	78	56
122	.	.	.	.	.
123	44	48.16	62.14	78	89
124	56	71.16	51.14	67	56
125	44	48.16	62.14	22	33
126	.	71.16	51.14	89	78
127	89	82.16	94.14	78	89
128	67	82.16	94.14	99	89
129	44	.	28.14	33	44
130	44	.	73.14	.	67
131	44	60.16	62.14	44	33
132	44	.	62.14	.	78
133	67	48.16	.	78	78
134	78	71.16	84.14	78	67
135	44	48.16	51.14	44	44
136	44	93.16	84.14	78	78
137	56	60.16	51.14	56	56

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES EIGHT, TEN AND FOURTEEN

------------------ TEACHER=1 CLASS=11 ------------------------

ID	L.C.8 CAT 1	L.C.8 CAT 2	L.C.8 CAT 3	L.C.10 CAT 1	L.C.10 CAT 2	L.C.10 CAT 3	L.C.14 CAT 1	L.C.14 CAT 2	L.C.14 CAT 3
1	33	33	33	33	56	44	44	67	56
2	33	33	33	33	67	56	33	50	50
3	33	33	56	50	78	89	56	61	89
4	22	33	33	50	56	78	.	44	.
5	.	.	.	.	.	.	.	.	.
6	33	33	.	33	89	56	67	56	33
7	.	.	.	.	.	.	.	.	.
8	33	33	33	0	78	33	33	39	44
9	33	33	33	33	78	56	33	78	44
10	33	44	33	33	56	.	.	67	89
11	33	33	33	33	56	89	22	61	67
12	33	33	99	50	78	.	56	56	67
13	.	.	.	.	.	.	.	.	.
14	22	33	67	17	78	89	11	67	78
15	33	33	56	50	78	78	67	67	56
16	33	44	67	33	89	67	.	56	67
17	.	.	.	50	67	99	33	56	50
18	33	33	33	33	67	22	33	67	72
19	33	33	44	67	56	44	33	33	44
501	.	.	.	33	56	33	.	56	44
502	44	44	89	33	78	99	67	89	72
503	33	33	33	50	78	.	33	67	99
504	22	33	33	33	89	78	.	56	50
505	33	33	33	33	99	89	67	94	89
506	33	.	56	50	.	44	67	56	.
507	33	33	78	0	67	56	22	61	56
509	33	33	33	0	78	89	33	78	67

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES EIGHT, TEN AND FOURTEEN

------------------- TEACHER=1 CLASS=14------------------------

ID	L.C.8 CAT 1	L.C.8 CAT 2	L.C.8 CAT 3	L.C.10 CAT 1	L.C.10 CAT 2	L.C.10 CAT 3	L.C.14 CAT 1	L.C.14 CAT 2	L.C.14 CAT 3
20	0	33	0	0	.	.	.	.	.
21	33	33	33	0	78	33	33	.	72
22	33	33	44	33	33	56	44	56	56
23	33	33	56	67	67	33	44	44	33
24	.	[illegible]	.	.	.	.	.	.	.
25	33	44	33	50	.	.	33	44	44
26	33	33	44	0	44	67	22	44	.
27	33	33	44	0	44	56	.	67	61
28	.	.	.	.	.	.	.	.	.
29	33	33	33	33	78	89	56	61	56
30	33	33	33	0	89	.	33	44	33
31	22	.	22	0	.	99	.	33	.
32	33	44	33	0	67	33	.	50	33
33	33	44	78	83	89	56	56	56	56
34	33	44	56	0	78	89	44	67	99
35	.	.	.	.	.	.	.	.	.
36	33	.	.	.	67	89	44	33	39
37	33	44	99	33	78	89	78	44	61
508	22	33	33	.	44	56	44	56	56
510	33	33	56	67	89	.	44	56	61
518	33	33	33	17	56	78	44	33	33
519	33	.	67	.	.	.	.	.	.

TABLE 2

STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS LEARNING CYCLES EIGHT, TEN AND FOURTEEN

------------------ TEACHER=1 CLASS= 16 ------------------------

ID	L.C.8 CAT 1	L.C.8 CAT 2	L.C.8 CAT 3	L.C.10 CAT 1	L.C.10 CAT 2	L.C.10 CAT 3	L.C.14 CAT 1	L.C.14 CAT 2	L.C.14 CAT 3
38	33	.	33	17	56	67	0	.	.
39	33	.	11	0	78	0	11	.	.
41	.	.	.	.	.	.	.	.	.
42	33	.	44	33	56	89	56	.	.
43	33	.	33	50	67	44	0	.	.
44	33	.	33	.	78	56	56	.	.
45	33	.	33	33	67	78	44	.	.
46	33	.	33	67	78	56	33	.	.
47	33	.	33	0	89	78	44	.	.
48	44	.	44	67	99	99	56	.	.
49	22	.	33	0	33	33	.	.	.
50	33	.	33	50	78	.	67	.	.
51	33	.	56	33	67	99	44	.	.
52	22	.	22	33	44	44	33	.	.
53	11	.	44	33	56	67	33	.	.
54	33	.	33	33	89	.	33	.	.
55	33	.	33	50	89	89	.	.	.
56	22	.	33	0	56	33	33	.	.
57	33	.	33	33	89	89	33	.	.
58	33	.	33	0	56	56	22	.	.
59	33	.	33	50	89	67	33	.	.
60	33	.	44	50	78	.	56	.	.
61	33	.	44	33	99	99	56	.	.
62	44	.	89	67	99	89	67	.	.
440	33	.	44	33	99	99	67	.	.
511	44	.	44	50	89	89	56	.	.
512	22	.	22	0	78	56	33	.	.
513	.	.	33	0	67	56	.	.	.
520	.	.	.	.	.	.	.	.	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES EIGHT, TEN AND FOURTEEN

------------------ TEACHER=2 CLASS= 21----------------------

ID	L.C.8 CAT 1	L.C.8 CAT 2	L.C.8 CAT 3	L.C.10 CAT 1	L.C.10 CAT 2	L.C.10 CAT 3	L.C.14 CAT 1	L.C.14 CAT 2	L.C.14 CAT 3
63	.	.	.	.	.	.	.	.	.
64	33	.	56	67	89	79	44	56	56
65	33	.	33	33	33	56	.	.	33
66	33	.	33	.	.	.	.	.	.
67	33	.	22	33	67	33	56	33	33
68	33	.	44	50	89	.	.	.	.
69	44	.	99	50	89	99	78	67	67
70	.	.	33	33	.	56	33	33	44
71	33	.	44	67	33	78	44	33	33
72	33	.	56	50	99	44	44	44	33
73	33	.	89	67	78	78	67	78	72
74	33	.	89	67	99	89	67	56	56
75	33	.	99	99	99	99	78	89	78
76	33	.	89	33	.	99	78	61	78
77	33	.	89	0	99	99	56	89	89
78	22	.	33	33	.	33	44	33	33
79	11	.	22	.	33	.	.	.	.
80	33	.	33	0	0	33	56	.	.
81	33	.	.	0	99	99	44	56	56
82	56	.	78	33	99	99	67	67	67
83	22	.	22	0	89	89	.	.	33
84	33	.	.	0	56	.	44	.	33
85	33	.	78	33	78	89	78	99	99
86	44	.	78	67	78	99	67	67	78
514	33	.	33	.	67	89	67	44	44
515	33	.	33	0	99	89	44	56	56
516	33	.	22	0	78	89	33	44	39
517	44	.	89	67	99	99	56	72	89
521	.	.	.	.	.	.	.	.	.
522	33	.	44	.	.	.	.	.	.

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES EIGHT, TEN AND FOURTEEN

------------------- TEACHER=2 CLASS=22 -----------------------

ID	L.C.8 CAT 1	L.C.8 CAT 2	L.C.8 CAT 3	L.C.10 CAT 1	L.C.10 CAT 2	L.C.10 CAT 3	L.C.14 CAT 1	L.C.14 CAT 2	L.C.14 CAT 3
87	33	.	44	50	.	.	33	78	61
88	.	.	.	.	.	.	.	.	.
89	.	.	.	.	.	.	.	.	.
90	33	.	33	50	89	.	33	56	33
91	33	.	33	50	99	67	56	56	56
92	22	.	33	.	33	56	.	44	39
93	33	.	44	0	67	33	67	44	33
94	33	.	33	50	78	56	67	67	56
95	33	.	33	67	89	89	.	78	33
96	33	.	33	33	33	56	.	33	44
97	33	.	33	33	78	33	44	44	33
98	33	.	56	33	99	78	44	99	94
99	22	.	33	33	89	89	44	50	61
100	22	.	33	33	78	89	67	39	33
101	33	.	33	50	89	99	33	.	44
102	11	.	33	0	33	56	22	89	56
103	.	.	.	.	.	.	.	.	.
104	33	.	33	33	99	78	56	44	33
105	33	.	33	33	56	89	.	33	44
106	33	.	33	33	78	78	56	67	56
107	33	.	33	50	.	56	33	33	44
108	22	.	33	0	89	78	56	61	33
109	33	.	33	99	89	99	78	94	89
110	11	.	56	33	78	89	67	89	61
111	33	.	89	33	78	89	78	99	78

TABLE 2
STUDENT SCORES ON COGNITIVE ACHIEVEMENT TESTS
LEARNING CYCLES EIGHT, TEN AND FOURTEEN

------------------- TEACHER=2 CLASS=25 -----------------------

ID	L.C.8 CAT 1	L.C.8 CAT 2	L.C.8 CAT 3	L.C.10 CAT 1	L.C.10 CAT 2	L.C.10 CAT 3	L.C.14 CAT 1	L.C.14 CAT 2	L.C.14 CAT 3
112	33	.	33	0	56	.	33	.	56
113	11	.	.	0	33	67	33	67	50
114	22	.	33	.	.	.	.	.	.
115	33	.	.	0	33	22	22	39	33
116	33	.	33	0	33	33	33	56	56
117	33	.	.	0	56	.	67	56	.
118	33	.	33	33	33	78	67	50	50
119	33	.	33	0	67	.	33	33	50
120	22	.	.	0	.	44	33	50	39
121	33	.	.	0	.	0	.	61	61
122	33	.	33	.	.	.	.	.	.
123	33	.	44	33	99	89	67	61	89
124	22	.	33	33	.	56	44	83	61
125	11	.	11	0	.	44	33	56	56
126	33	.	.	.	.	99	.	78	56
127	33	.	89	33	78	99	78	89	89
128	44	.	56	99	.	89	67	94	89
129	33	.	33	0	33	33	33	50	44
130	33	.	33	33	78	56	.	.	33
131	22	.	.	0	.	.	11	44	44
132	33	.	56	50	99	67	.	56	33
133	33	.	33	0	33	.	33	33	44
134	33	.	56	33	99	89	56	61	50
135	33	.	44	67	44	44	44	78	61
136	44	.	44	33	56	99	33	83	72
137	33	.	33	0	.	22	33	44	50

Appendix 4A

LC-2 Student Materials

INVESTIGATION 2

Name____________________

GATHERING DATA
SALT AND CALCIUM

Section__________________

A. Clean and dry your 100 ml and 150 ml beakers and two watch glasses. Weigh each of them 3 times. Record the weights to two decimal places.

	100 ml beaker		150 ml beaker
	____________g		____________g
	____________g		____________g
	____________g		____________g
average	____________g	average	____________g

NOTE: Round your average weight to two decimal places.

B. In one of the beakers place a spoonful of salt (sodium chloride--NaCl), and in the other beaker place a designated amount of calcium metal (Ca).

C. Weigh each beaker, a watch glass, and its contents three times and record the weights to two decimal places.

	100 ml system and ____________		150 ml system and ____________
	____________g		____________g
	____________g		____________g
	____________g		____________g
average	____________g	average	____________g

D. From your data, determine the weights of salt and calcium contained in the systems. Show your calculations.

Salt

Calcium

E. Add 25 ml of distilled water to the beaker containing salt. Replace the watch glass and record careful observations of the interaction between salt and water.

F. After the observations are written, test the remaining solution for conductivity and with litmus paper. Record the results of these tests.

G. Transfer the salt system to a ring stand. Heat the system strongly until it is completely dry. While this system is heating, you may begin working with the calcium system.

H. Add 25 ml of distilled water to the beaker containing calcium. Replace the watch glass and record careful observations of the interaction between calcium and water.

I. Test the remaining liquid for conductivity and with litmus paper. Record the results of the tests.

J. When the salt system is completely dry, remove it from the ring stand and place the calcium system on the ring stand. Heat the calcium system strongly until it is completely dry.

K. As the dried systems cool to room temperature, weigh each system and record the weights.

	salt system		calcium system
	___________g		___________g
	___________g		___________g
	___________g		___________g
average	___________g	average	___________g

L. Determine the weights of the substances remaining in the two beakers.

M. Compare these weights to those obtained in section D.

N. Calculate the percentage weight change in the salt system. Clearly label the values used in your calculation.

O. Calculate the percentage weight change in the calcium system. Clearly label the values used in your calculation.

THE IDEA
QUESTIONS

Name____________________
Section__________________

1. What differences are there between the calcium system and the salt system?

2. What conclusions can be drawn about the interactions in these two systems?

4A-5

EXPANDING THE IDEA
PHYSICAL AND CHEMICAL?-DEMONSTRATION

Name____________________
Section__________________

NOTES

A. Calcium and water
    1. Describe procedure.

    2. Record your observations.

    3. Is this a physical or chemical change?

    4. What did you observe to support that it was a physical or chemical change?

B. Copper sulfate and ammonium hydroxide
    1. Describe procedure.

    2. Record your observations.

    3. Is it a chemical or physical change?

4. What did you observe to support that it was a physical or chemical change?

C. Aluminum and hydrochloric acid

1. Describe procedure.

2. Record your observations.

3. Is this a physical or chemical change?

4. What did you observe to support that it was a physical or chemical change?

EXPANDING THE IDEA
READING 2

FOOD FOR THOUGHT AND BREAKFAST

Many common systems, which seem to be simple and uninteresting, can actually be very complex and exciting, if they are carefully observed. Take, for example, a pan of water containing a raw, uncracked egg. That system would seem to be sufficiently uninteresting, at first glance, and it would probably continue to be unless we did something to it. We will, therefore, put our simple, uninteresting system on the stove and begin heating it.

"How complex and exciting!", you say, as the system begins to get warm. Well, maybe not yet, but we have only begun to observe. One of the first things we see is the formation of many small bubbles on the bottom and sides of the pan, as well as on the surface of the egg. After a while, these bubbles rise to the surface and are gone from the system. We can also notice that the egg moves around in the pan; not very much at first, but then it moves more and more as the water gets hotter. Both of these observations are important, and explaining them would give us much useful information. We will, however, pass by those observations for now and center our attention on the "big" things that are happening to the water and the egg.

Before very long, during this heating process, there are sounds coming from the system. Some of these sounds are light, pinging sounds and others are louder, resembling a very mild explosion. What is causing the noise? Careful observation shows bubbles forming at the bottom of the pan, but these bubbles are behaving differently from the very first ones to form. We could watch the first bubbles come all the way to the surface, but most of the bubbles that are forming now disappear before they get to the surface! Since these bubbles are formed at the bottom (where the system is hottest) and collapse on the way to the surface (where the system is coolest), maybe the collapsing is caused by the water cooling the bubble. If this happens rapidly, the collapsing of the bubble (implosion) could cause a shock wave that we could hear. The bigger the collapsing bubble, the bigger the shock wave. As we continue to watch, we see that the bubbles get closer and closer to the surface before imploding. Finally, the water gets hot enough that it cannot cool the bubble, as it rises, and the bubble breaks the surface of the water. This condition is, of course, called boiling.

If you hold your hand at a safe distance above the pan of boiling water, you notice that your hand gets damp. If you hold something cold over the pan (a glass of ice water, for example), the glass gets very wet on the outside. It is [illegible] shock to find out that the liquid on the glass is water--maybe "flat" tasting, but still water.

Having looked carefully at the water in the system, let us now turn our attention to the egg. In discussing the egg, we will have to use information from other work and observations taken at other times. (This is usually necessary any time we make intelligent observations or do sensible experiments). We know what the raw egg looked like inside before we started heating the system.

The "white" was not white at all, but transparent, and both the yolk and white were fluid. What the inside will look like after the heating process will depend on how long we heat the egg, but we know basically that the "white" will be white and less fluid, and the yolk will be more yellow than it was and less fluid.

Let's assume, for the sake of discussion, that we stop the heating process several times and examine the inside of the egg. In reality, of course, this would require several eggs because we would have to break them to observe the inside. If the egg is examined soon after the heating process is begun, we will see little, if any, change from the "raw" state. Later examination, however, would show no change in the yolk, but the white would have begun to change from clear to white. Most of the observable change would be near the shell. As we continue to observe eggs later in the heating process, we notice that the change extends continually farther in toward the center. The changes occurring in the egg, as in the water, must be caused by the heat applied to the system. Furthermore, the application of heat seems to be fairly uniform on all parts of the egg; that is, the bottom part is not changing more rapidly than the top part. Fortunately, this egg heating process is predictable. You know, for example, that if you want a soft-cooked egg it will have to cook for about three minutes after the water begins to boil. If, on the other hand, you want a hard-cooked egg for breakfast, you can begin heating the system and go jog a mile or two.

We have seen clearly defined changes occurring in both of the major parts of our system. The changes, though caused by the same heating, have been quite different. The changes in the water will be called "physical" changes, and the changes in the egg will be called "chemical" changes. Let's note some differences between the two types of changes.

The process of boiling could be reversed by simply removing heat, but the egg did not become raw as a result of cooling down. The changes in the egg, therefore, were irreversible by physical means. There were changes in color, when the egg cooked. Several other properties, such as texture, odor, and taste, changed as a result of cooking the egg. (If you don't believe that the taste changed, you can perform the obvious experiment). So, in summary, we see that the water that underwent change was still water after the change, but the egg (though still recognizable as the day's work of a hen) had changed in its chemical makeup. You have seen other observational evidence of chemical change also, which you will recall by reviewing your laboratory experience.

It is important to note that one cannot always determine that a chemical change has occurred by observing only one evidence for chemical change. For example, a gas was produced when water boiled, but no chemical change occurred. It would also be possible to change the color of a metal, by heating it, without changing the metal chemically. It will be wise, therefore, to know conditions under which changes take place before deciding whether the change is physical or chemical. It will also be wise to look for two or more evidences of chemical change before making your decision.

Although we have looked rather closely at this system, there are still many questions at which we have not even looked. For example:

- Why were there "waves" in the water when it was being heated?
- Why does the water that formed on the cold glass taste "flat"?
- What is the source of the stream of bubbles coming from one end of the egg?
- How does the egg get heated so uniformly?

As we continue our study of chemistry, it is quite possible that we will be able to give reasonable answers to these and other questions that could be asked about our complex and exciting system. Okay, so maybe it still isn't exciting, but at least it's complex (and informative).

Appendix 4B

LC-2 Invention Lecture Notes

LC-2 Invention Lecture

Announce subject = chemical and physical change.

Define chemical change = change in matter that cannot be reversed by physical means.

Define physical change = change in matter that can be reversed by physical means.

(Definitions to be written up)

Two questions come to mind regarding these definitions:
1. What does it mean to reverse a change by physical means?
2. How would you be able to tell the difference between a chemical and physical change?

referring to Question 1;
  a. iron (III) chloride was dissolved in water; solid initially yellow, solution also yellow.
  b. If water were taken away (by boiling), iron (III) chloride would be left-physical change.
  c. (another example) If a piece of metal is ground into smaller pieces or a powder, it is still the same metal but in a different form.
  d. (third example) If liquid water is sufficiently cooled, it freezes into solid water (ice), which can be changed back (reversed) to liquid water by simply adding heat (physical means)

referring to Question 2;
  a. List several observations that would indicate chemical change (note that this list is not necessarily exhaustive, but representative): gas, heat, precipitate, color change, texture change, litmus change, conductivity change, weight change.
  b. After these things are written down, they can be talked about individually, providing definitional information as needed (e.g., precipitate).
  c. Use the rusting of iron and the burning of a candle to illustrate as many of the observational evidences as possible.
  d. Relate how multiple observations are sometimes necessary and that the context of the change is important. This can be done by reviewing the examples cited for physical change and pointing out that some observations made there could also be made in systems involving chemical changes.

Appendix 4C
CAT Tests for LC-2

Name________________
Section______________
Date________________
Code_____LC2-________

Changes in matter can be broadly classified in two ways:

1. changes which can be reversed by simple changes in the environment; and

2. changes which cannot be reversed by simple changes in the environment.

For each of the following changes, classify the change as reversible or non-reversible by simple means. Also, explain how to reverse it, or explain why it cannot be reversed by simple means.

1. Dry ice disappearing

   a. ____________reversible ____________non-reversible
   b. explanation

2. Shredding cheese

   a. ____________reversible ____________non-reversible
   b. explanation

3. Making dried apricots

   a. ____________reversible ____________non-reversible
   b. explanation

4. Iron hammer rusting

a. ____________reversible ____________non-reversible
b. explanation:

5. Burning alcohol

a. ____________reversible ____________non-reversible
b. explanation:

6. Cleaning a paint brush with turpentine

a. ____________reversible ____________non-reversible
b. explanation:

7. Digesting food

a. ____________reversible ____________non-reversible
b. explanation:

Name____________________
Section__________________
Date____________________
Code______LC2__________

Changes in matter can be broadly classified in two ways:

1. changes which can be reversed by simple changes in the environment; and

2. changes which cannot be reversed by simple changes in the environment.

For each of the following changes, classify the change as reversible or non-reversible by simple means. Also, explain how to reverse it, or explain why it cannot be reversed by simple means.

1. Water evaporating from a lake

   a. ____________reversible ____________non-reversible
   b. explanation:

2. Wood changing to coal

   a. ____________reversible ____________non-reversible
   b. explanation:

3. Shredding paper

   a. ____________reversible ____________non-reversible
   b. explanation:

4. Cleaning a greasy pan with detergent

a. ___________reversible ___________non-reversible
b. explanation:

5. Leaves turning color in autumn

a. ___________reversible ___________non-reversible
b. explanation:

6. Making beef jerky

a. __________reversible __________non-reversible
b. explanation:

7. Running a gasoline engine

a. __________reversible ___________non-reversible
b. explanation:

Name ____________________
Section ____________________
Date ____________________
Code LC2- ____________________

Changes in matter can be broadly classified in two ways:

1. changes which can be reversed by simple changes in the environment; and

2. changes which cannot be reversed by simple changes in the environment.

For each of the following changes, classify the change as reversible or non-reversible by simple means. Also, explain how to reverse it, or explain why it cannot be reversed by simple means.

1. soda pop fizzing

   a. ____________reversible ____________non-reversible
   b. explanation:

2. making powdered sugar

   a. ____________reversible ____________non-reversible
   b. explanation:

3. setting off a firecracker

   a. ____________reversible ____________non-reversible
   b. explanation:

4. silverware tarnishing

a. ___________reversible ___________non-reversible
b. explanation:

5. celery becoming limp

a. ___________reversible ___________non-reversible
b. explanation:

6. sweetening iced tea

a. ___________reversible ___________non-reversible
b. explanation:

7. tomatoes ripening

a. ___________reversible ___________non-reversible
b. explanation:

Description, Rationale, and Grading Criteria for LC-2 CATs

LC-2 was performed very early in the school year. As a consequence of the placement of this LC, the responses of the students were not expected to be worded in precise, technical language. The subject of LC-2 was physical change and chemical change, and the CATs were designed to elicit responses that would indicate the extent to which a student understood the concepts of physical and chemical change and the difference between physical and chemical change. To the extent that students showed an understanding of these concepts, they received scores in accordance with the general scale discussed in Chapter 2 of this report.

The information given at the beginning of each of the CATs alluded to the general definitions for chemical and physical changes that were developed during LC-2. Specific terminology used in those definitions was altered to avoid providing a cue to a memorized response.

There were seven questions on each of the three forms of CATs for LC-2. Four questions on each test were judged to relate to physical changes, and three questions related to chemical changes. The breakdown of question types on the three forms follows. Copies of the CATs are in Appendix 4C.

	Form "a"	Form "b"	Form "c"
Question 1	physical	physical	physical
Question 2	physical	chemical	physical
Question 3	physical	physical	chemical
Question 4	chemical	physical	chemical
Question 5	chemical	chemical	physical
Question 6	physical	physical	physical
Question 7	chemical	chemical	chemical

Each question contained an (a) and a (b) part, which were graded in conjunction. Since a given question could refer to a physical change or a chemical change, the grading criteria will make reference to responses that would apply to both situations.

Criterion 3: (1) A physical change can be reversed by physical means, or

(2) A physical change does not change the character of the substance.

(3) A chemical change is not reversible by physical means because the nature of the substance has changed.

Criterion 2: The response is correct and pertinent, within the scope of Criterion 3, but it is incomplete (e.g.; a new substance is formed, but there is no indication of a change in the substance); or there is no connection or distinction made between the new and old substances.

Criterion 1: The response indicates a misunderstanding of the nature of physical and chemical changes.

(1) Assertion of an inconsistent or erroneous statement;

(2) Attributing properties to substances that no substances have; or

(3) Giving a correct or incorrect answer to the (a) part of the question and a "non-answer" to the (b) part of the question. A "non-answer" would include an essential restatement of the question.

NOTE: In order to receive a grade of 3, 2, or 1, an answer must include some response to the (b) part of the question.

Criterion 0: (1) Answer is left blank;

(2) There is no attempt at the (b) part; or

(3) A nonsense answer for the (b) part.

This single scale was applicable to all three forms of tests. Actual example responses that fit the foregoing criteria have been selected from Form "a" of the test (Appendix 4C-1 and 4C-2).

Examples of Criterion 3 Responses

Question 3: (a) reversible. (b) "All it is is removing the water. It can be replaced. It is a physical change."

Question 3: (a) reversible. (b) "Because you can add water to them and they would be the same."

Question 5: (a) non-reversible. (b) "Once the alcohol has been burned, it has been changed into a new substance and could not be restored to its original form."

Question 5: (a) non-reversible. (b) "Since there is a release of heat, release of gas, and release of light which are all signs of chemical changes, then the change is non-reversible."

Question 5: (a) non-reversible. (b) "Once it is burned (broken down) and becomes part of the atmosphere, there is no way to rejoin the molecules in original form."

Occasionally, students selected an incorrect choice for the (a) part, but the explanation given in the (b) part indicated a clear understanding of the concepts of physical and chemical change. In such cases a 3-grade was given. This type of response is shown by the examples that follow.

Question 3: (a) non-reversible. (b) "After you have dried the juices, water and other liquids out of an apricot, you cannot add them again to get a fresh apricot. If you did add them, the apricot would not taste nearly as good as it would have before you dehydrated it."

Question 3: (a) non-reversible. (b) "Once an apricot has been dried it cannot be restored to its original freshness. The sun's rays would have permanently altered the apricots molecular structures."

Examples of Criterion 2 Responses

Question 2: (a) reversible. (b) "Cheese can be melted."

Question 6: (a) reversible. (b) "The turpentine just alters the form of the paint."

Question 4: (a) non-reversible. (b) "Because you can't make it unrusty, unless you change it."

Question 7: (a) non-reversible. (b) "Because it is all mixed up and has had other chemicals to help digest it, and if you try to put the food back the way it is it will be changed."

Examples of Criterion 1 Responses

Since Criterion 1 deals with content misconceptions, examples of commonly occurring misconceptions will be listed for each question.

Question 1: (a) non-reversible. (b) "Gas mixed with the air and you can't get it back."

Question 1: (a) non-reversible. (b) "The ice has evaporated into gas and has floated away."

Question 1: (a) non-reversible. (b) "Non-reversible because it forms the mist that floats off; it's a chemical change."

Question 2: (a) non-reversible. (b) "The environment can't mold the cheese back together."

Question 2: (a) non-reversible. (b) "Because once you have shredded the cheese some of the matter is taken away when you cut it and you can't replace it."

Question 2: (a) non-reversible. (b) "Once a person shreds cheese, he/she can't simply squeeze it back together, or even melt and mold it back to its original form."

Question 3: (a) non-reversible. (b) "Once they are dried, they cannot go back to regular apricots."

Question 3: (a) non-reversible. (b) "The apricots when dried cannot regain moisture because they are dead and have lost the processes to do so."

Question 3: (a) non-reversible. (b) "Can't be made back into a ripe apricot. It needs the tree to ripen."

Question 4: (a) reversible. (b) "You can clean the rust off with a certain chemical, then use it again."

Question 4: (a) reversible. (b) "Put the hammer in a warm and dry place and this will stop the rusting."

Question 4: (a) non-reversible. (b) "If an iron hammer gets moisture on it, then it will rust and there's no way of stopping it."

Question 5: (a) non-reversible. (b) "Once alcohol is burned, there is no possible way to reverse the change because burnt alcohol evaporates into the air."

Question 5: (a) reversible. (b) "You could take the oxygen away from it and it would go out."

Question 6: (a) reversible. (b) "If you clean the brush with turpentine then you can use the brush again."

Question 6: (a) reversible. (b) "Put it back in the paint."

Question 6: (a) non-reversible. (b) "As soon as the paint is off in the turpentine, you can't put it back on. It dissolves."

Question 7: (a) reversible. (b) "When something is bothering your stomach or intestinal organs, you throw up."

Question 7: (a) non-reversible. (b) "There isn't a way you can once you eat something make it not digest because it's an automatic function of the body."

Question 7: (a) non-reversible. (b) "Once the food is digested it can't be run back through your system and become whole again."

Appendix 5A
LC-5 Student Materials

INVESTIGATION 5
COMPOSITION OF A COMPOUND

Name____________________

Section____________________

GATHERING DATA

A. Gently heat your evaporating dish and crucible cover for 2 or 3 minutes, then heat this system strongly for 3 minutes. Allow the system to cool.

B. Accurately weigh the empty evaporating dish with the crucible cover to two decimal places.

____

____

____

average ____________________

C. Obtain a strip of magnesium metal ribbon from your teacher. Scrape off the adhering film with the fine steel wool and then wipe the ribbon with a clean paper towel. Cut the metal into small pieces and place them into the evaporating dish. Weight the system to two decimal places.

____

____

____

average ____________________

D. Using your data, calculate the weight of magnesium metal in the system. Show your work.

E. Heat the covered evaporating dish and magnesium system gently for 2 minutes, gradually increasing the heat intensity. Continue heating the system strongly for an additional 15 minutes, then turn off the burner.

F. As the system is cooling, visually inspect the contents of the system. Record your observations.

G. After the evaporating dish has cooled, add only enough distilled water to the dish to cover its contents. Gently heat the evaporating dish. As the water boils away, smell the vapors coming from the evaporating dish and identify them. After the water had evaporated, continue to strongly heat the system for 5 minutes. Heat to constant weight.

H. Determine the weight change in the system. Show your work.

I. Record careful observations of the final contents of the evaporating dish.

J. You have now calculated two weights: the weight of magnesium and the weight gained (or lost) during reaction. There are four mathematical operations (addition, subtraction, division, multiplication) available to manipulate these weights. Use these operations on the weights and fill in the chart below. Include units, when appropriate.

wt. Mg + wt. chg.	wt. Mg - wt. chg.	$\frac{\text{wt. Mg}}{\text{wt. chg.}}$	wt. Mg x wt. chg.

THE IDEA
QUESTION

Name____________________
Section_________________

1. What substances could possibly have reacted with the magnesium? (i.e., What are the substances available to the system?)

2. Which of the four mathematical operations in section J would you expect to give the same value, no matter how much Mg was used? Why?

EXPANDING THE IDEA
HEATING HYDRATED COPPER (II) SULFATE

Name____________________

Section__________________

PART I

A. Place a small amount of hydrated copper (II) sulfate in a test tube. Heat the test tube with a bunsen burner. Record your observations.

B. Allow the test tube to cool and then add a few drops of water to the solid in the test tube. Record your observations.

PART II

A. Gently heat your evaporating dish and crucible cover for 2 to 3 minutes, then heat this system strongly for 3 minutes. Allow the system to cool.

B. Accurately weight the empty evaporating dish with crucible cover to two decimal places.

____

____

____

average ____________________

C. Add between 1 and 4 grams of hydrated copper (II) sulfate to the evaporating dish and weigh the system to two decimal places.

____

____

____

average ____________________

D. Calculate the weight of hydrated copper (II), sulfate used. Show your work.

E. With the crucible lid slightly open, heat the evaporating dish gently twelve-fifteen minutes, then turn off the burner.

F. As the system is cooling, visually inspect the contents of the system for evidence of complete reaction.

G. After the crucible has cooled, weigh the system, and then heat gently to constant weight.

______________ ______________ ______________ ______________

______________ ______________ ______________ ______________

______________ ______________ ______________ ______________

______________ ______________ ______________ ______________

H. Determine the weight of the residue in your system. Show your work.

I. Determine the weight change in the system. Show your work.

QUESTIONS

1. The chemical formula for hydrated copper (II) sulfate can be written, $CuSO_4 (H_2O)_x$, where x represents a number of H_2O molecules. What are the possible products of heating this substance?

2. Did the weight increase or decrease when you heated the hydrated copper (II) sulfate - $CuSO_4(H_2O)_x$? Offer an explanation for the change.

3. Divide the weight change by the weight of the residue. Show your work and explain what this number represents.

4. Use the weights on the periodic table to determine the best value of "X" in $CuSO_4(H_2O)_x$. X should be an interger. Show your work.

EXPANDING THE IDEA
READING 5

THE CHEMICAL CONGRESSMEN

Congress for over two centuries has been instrumental in formulating the laws of the land. Those involved have gathered information, weighed facts, and have finally arrived at judgements affecting the nation as a whole. In a similar fashion, various chemists in centuries past have compiled laboratory observations, made hypotheses, developed theories, and established chemical laws. Just as civil laws may be stricken from the books because they are no longer applicable, even so chemical laws sometimes must be revised when new experimental information is made available.

The history which surrounds the development of the foundations of modern chemistry is fascinating and no one man can be credited with all of the discoveries. Several scientist's lives and findings will serve to demonstrate three chemical laws that have been formulated.

The Congressman from France (1743-1794)

Although Antoine Laurent Lavoisier is viewed as the "father of modern chemistry", we should remember that he is not without predecessors who were instrumental in shaping his theories. Joseph Priestly (1733-1804), to whom we owe the fizz in carbonated beverages, had shown that when mercuric oxide (then called mercury calx) was heated, a gas was produced which caused a candle to burn "with a remarkably vigorous flame". He breathed some of this "air" and remarked after experiencing its invigorating effects, "Who can tell but that, in time, this pure air may become a fashionable article in luxury." [1]

Lavoisier repeated the experiment, naming the gas oxygen. Why should copying another chemist's experiment, be so important to the scientific community? It shouldn't, except that our Frenchman examined another facet of the reaction that Priestly had not bothered to check. He weighed the system before and after the reaction. This may not sound like a momentous innovation (especially since we have been weighing nearly everything three times). In the eighteenth century, though, scientists were primarily concerned with qualitative descriptions of substances. That is, they were interested in describing physical changes in systems, for example, the changing of a metal into a non-metal by the addition of heat. Visual observations are extremely important, but they are further enhanced by quantitative data. Isaac Newton and Galileo proved to physicists, initially, that measuring the size of objects, their mass, and the time it took them to move through a certain distance was important when analyzing the motion of the planets. Lavoisier, though not the first to do so, simply applied these principles to chemistry.

What did he find? Well, when the mercuric oxide was heated after accurate weighing, it lost weight. He had begun with 216 grams of a red powder and finished with 200 grams of quicksilver, liquid mercury. The gas was trapped and consequently weighed. . . You guessed it; 16 grams of oxygen had been produced. The mass of the reactants equaled the mass of the products. We now call this principle the law of the conservation of mass in a chemical reaction.

---

[1] A Short History of Chemistry, J. R. Partington, Harper and Brothers, New York, 1960)

$$\underset{\text{mercuric oxide}}{216\text{ g.}} \longrightarrow \underset{\text{mercury metal}}{200\text{ g.}} + \underset{\text{oxygen}}{16\text{ g.}}$$

Lavoisier went on to prove this law in reaction after reaction, but let us move on to the next chemist.

Yet Another Congressman from France (1754-1826)

Joseph Proust believed, on the basis of his experimental observations, that compounds were not haphazard in their composition. That is, a particular substance had particular portions of each element in it. (For example, Mercuric sulfide contained a certain amount of mercury and a fixed amount of sulfur.) Again, this hypothesis may sound simplistic. But remember, chemistry was becoming quantitative at this time and many observations were still purely qualitative. Chemists and Alchemists alike knew well that mercury and sulfur were the components of mercuric sulfide, but some held that the amounts of each were widely flexible. Some of the confusion was brought on by the fact that metallic alloys and various glasses can be formed in indefinite proportions. This knowledge did not sway Proust. He contended rightly that these substances were mixtures (today we might also call them solid solutions) and not compounds produced by chemical reactions. How could he be so certain? Mr. Proust had based his strong convictions on many observations of chemical combination.

One such experiment dealt with copper (II) carbonate $CuCO_3$. He obtained this compound from several natural sources and also prepared it in the laboratory. Each sample, regardless of its source, was found to contain a definite amount of copper combined with a definite amount of carbon and oxygen. Proust's research proved convincing to most of the scientists of his day and his theory is now known as the law of constant composition.

The Congressman from England (1766-1844)

John Dalton, by his own admission, was not a brilliant scientist. Perseverence in the laboratory was his primary asset, and we find that he had to be diligent considering his perceptual handicap. He was color blind, an obvious problem for the research chemist.

In the course of his study, Dalton analyzed many substances to determine their composition. He found that the proportion of oxygen to carbon in carbon dioxide - CO_2 - was twice that in carbon monoxide - CO. Given two equal portions of carbon, he also discovered that twice as much methane gas - CH_4 - could be produced as ethene gas - C_2H_4. Various substances, then, not only had constant compositions as stated by Proust, but their elements were combined in whole number ratios. We call this principle the law of multiple proportions.

It is interesting to note that although Dalton was the first to develop the law of multiple proportions, he was not able to apply it accurately to every substance he tested. He falsely reasoned that the most common combination of two elements in nature should be the simplest possible, one to one. On this assumption, water would have been known as "good old" HO. Ammonia, by the same premise, was NH, instead of NH_3. Forty more years of research were necessary to clear up this problem of compound formulas, but Dalton proved well that the law of multiple proportions was here to stay.

Lavoisier, Proust, and Dalton compose an extremely small portion of all the "law makers" who have contributed to the body of chemical knowledge. These chemists simply set forth some of the first and most fundamental principles which aid us every time we enter the laboratory. More laws are left to be uncovered, more than have yet been revealed.

READING 5
QUESTIONS

Name____________________
Section_________________

1. Determine formulas for the following compounds of nitrogen and oxygen (show your work).

Compound	wt. of nitrogen (g)	wt. of oxygen (g)
A	1	2.85
B	1	2.28
C	1	0.57
D	1	1.71

2. Samples of gas composed of carbon and oxygen were collected from two sources. Source A was exhaust gas from a gas burner, and source B was an enclosed terrarium containing plants. Using the data below, determine what the two gases are (show your work).

Source	wt. of carbon (g)	wt. of oxygen (g)
A	5.0	13.3
B	0.3	0.8

3. Which of the three laws discussed in this reading are illustrated by question 1 and question 2? Explain.

4. Which of the three laws discussed in this reading is illustrated by the heating of magnesium in investigation 5? Explain.

5. Which of the three laws discussed in this reading is illustrated by the heating of hydrated copper (II) sulfate in investigation 5? Explain.

Appendix 5B

LC-5 Invention Lecture and Discussion Notes

INVENTION DISCUSSION GUIDELINES

CONCEPTUAL INVENTION--THE IDEA

One of the central inventions of this investigation is that element weights are unique and useful in determining compound formulas. To this end the students have been instructed to manipulate the data according to the four basic mathematical operations. The discussion of this investigation begins, however, by examining--from experimental evidence and logical reasoning--the possible results of the reaction that took place. Guidelines for this discussion follow.

A. Ask the class to supply a list of reactants available to the magnesium. Write these on the board in equation form as they are suggested (e.g., $Mg + O_2 \longrightarrow$).

B. When the list is completed, lead the class in predicting products of these reactions and then in balancing the equations. Formulas for some predicted products will need to be supplied by the teacher while others, such as that of magnesium oxide, can be given by students.

NOTE: Initially, all possible reactants should be given consideration. Some, such as argon, can soon be dismissed due to their "noble" nature, but others, such as carbon dioxide should be given a more detailed treatment. Allow the class to predict products (in terms of which elements are combined in compounds) and to support their attempts with some sort of evidence. For example, some students have suggested that, since there was some black solid present after the heating, carbon dioxide could have reacted with the magnesium to form magnesium oxide and carbon.

C. The net result of the foregoing discussion should leave only equations producing magnesium oxide and magnesium nitride, as follows.

$$2Mg + O_2 \longrightarrow 2MgO$$

$$3Mg + N_2 \longrightarrow Mg_3N_2$$

D. Ask the class the purpose for adding water to the reacted system. If the students have trouble with that question, ask for their observations as they heated the system to drive off the water. Lead the discussion to an equation representing the reaction of magnesium nitride and water to produce ammonia and magnesium oxide. By this time in the discussions of the reactions, it should be apparent to the students that all reaction possibilities eventually lead to the formation of magnesium oxide.

E. Using the equation that reacts magnesium with oxygen to produce magnesium oxide, invent "synthesis reaction".

F. Make column headings on the board that correspond to the ones in THE IDEA. Add one more column labeled "initial weight of magnesium." Ask a member from each group to record the information from that group on the board.

G. When all the data are listed and copied down by the students, lead a discussion about the information provided by the four data manipulations. A discussion of units is appropriate.

NOTE: It would be wise to ask the students what substance is represented by the weight change. From this point on, the weight change can be referred to as oxygen weight.

H. Question the students about the meaning of the ratio (comparison). Be sure that the students have some understanding of this relationship before continuing.

I. The students have had to accept the formula for magnesium oxide on the teacher's authority. Ask the class if these data ratios can be used to show that MgO is a proper formula for magnesium oxide. Through discussion and questioning, present the idea that the periodic table lists weights for one "unit" of each element. Ask the class to calculate the weight ratio of one magnesium and one oxygen from the weights given on the periodic table.

J. Compare the table ratio obtained above to the experimental ratios. Discuss discrepancies, average the experimental ratios, etc., but conclude the discussion by gaining consensus on the viability of the formula.

Invention lecture (Investigation 5)

Chemical compounds are put together in definite proportions by number of atoms and by weight.

Carbon dioxide (CO_2) contains one carbon atom and two oxygen atoms, as indicated by its formula. Carbon monoxide, on the other hand, contains only one carbon atom and one oxygen atom.

Other examples of compounds include: water (H_2O), magnesium nitride (Mg_3N_2), iron (III) chloride ($FeCl_3$), cyclohexane (C_6H_{12}), and potassium carbonate (K_2CO_3).

Compounds are assembled in definite proportions by weight. This is because each of the elements has a different weight. (Point out the location of weights on the periodic table and go over a few examples.)

Magnesium nitride (Mg_3N_2), for example, could be made by combining 72.9g of Mg (24.3 x 3) with 28g of nitrogen (14 x 2). Note that 75g of Mg combined with 28g of nitrogen would result in extra magnesium.

Here is an example of a way in which weights of elements in a compound can be used to determine the compound's formula. The first example compound will contain 4.3g of chromium and 2.6g of sulfur.

1. Notice that we have said that compounds are put together in definite proportions by weight, so the ratio (comparison) of the chromium weight to the sulfur weight is:

$$\begin{matrix} Cr \\ S \end{matrix} \quad \frac{4.3g}{2.6g} = 1.6.$$

2. If we assume, that the compound contains one chromium atom for each sulfur atom (the simplest possible formula), a ratio of weights from the periodic table would be:

$$\begin{matrix} 1 - Cr \\ 1 - S \end{matrix} \quad \frac{52}{32} = 1.6.$$

3. Since the two weight ratios are the same, we can conclude that the correct formula for the compound is CrS, indicating one chromium and one sulfur.

Another example is a compound containing 4g. of iron and 1.7g of oxygen. (Work this out as in the example above, but the formula will be Fe_2O_3.)

I5 Expansion Discussion Guidelines
Necessity Experiment

1. What observations did you make when the copper (II) sulfate was heated in a test tube?

2. What happens when water was added to the test tube?

3. Describe the residue in the crucible after heating.

4. Q.1 - Have the students list the possible products of heating $CuSO_4(H_2O)_x$. The students should use laboratory evidence to support the possible products.

5. Q.2 - The weight change represents the relative weight of water vs $CuSO_4$. Again, the students should use laboratory evidence to explain the change in weight.

6. Q.3 - Discuss the significance of the constant value for the weight change divided by the weight of the residue. Stress the definite proportion concept for both weight and number of particles.

7. It might be a good idea to challenge the student's assertion that the liquid in part I is water. Introduce the $CoCl_2$ test paper during the discussion.

8. Q.4 - Work through Q. 4 and discuss its significance.

9. Discuss Reading 5, "The Chemical Congressman" and the questions. The questions center around the law of constant composition and the law of multiple proportions.

Appendix 5C

CAT Tests for LC-5

Name______________________
Section____________________
Date______________________
Code____LC5-_______________

A compound is made of two elements, X and Y. Which of the following experimental observations would be necessary to determine the formula for the compound. Circle the necessary criteria. (There may be more than one choice.)

weight of X in the compound

weight of Y in the compound

melting point of the compound

density of the compound

total weight of the compound

weight of one atom of X

weight of one atom of Y

Explain how this information would be used to determine the formula for the compound.

5C-2

Name______________________
Section____________________
Date______________________
Code LC5-

Table 1 on the next page contains information which might be useful in answering the following questions.

1. The following list of chemical formulas represent compounds. Circle those which could be the same compound. Explain your choice.

   a. CH C_6H_8 H_3C C_2H CH_2 CH_4 C_3H_6

   b. explanation:

2. A sample of a compound is analyzed and found to contain 2.0 grams of nitrogen (N) and 5.1 grams of chlorine (Cl). What other information do you need to determine the formula of the compound? Explain your answer.

   a. information needed:

   b. explanation:

3. A compound is analyzed and found to contain 5.0 grams of sulfur and 5.0 grams of oxygen. Determine the formula for this compound. Show your work.

TABLE 1

Element	Symbol	Atomic Weight
Carbon	C	12.0
Hydrogen	H	1.0
Oxygen	O	16.0
Sulfur	S	32.0

Description, Rationale, and Grading Criteria for LC-5 CATs

In learning cycle 5 we were testing for the concept that compounds are put together in definite proportions by weight and by number of atoms. The general criteria used to score the student responses on the content achievement tests is described in Chapter Two.

There were two forms of the CATs in learning cycle 5 (see Appendix 5). The pretest (Form A) consisted of a two part question with only one score being assigned. For convenience in describing the scoring criteria, the choices in part one were labeled (a) through (g). This question was scored using the following Criteria.

CAT Form A Learning Cycle 5

A score of ______ was assigned	if the answer to
3	part one was one of the following combinations a,b,f,g a,e,f,g b,e,f,g a,b, if f and g are used in the explanation in part (b) AND part two the student compared the ratio of the atomic weights to the ration of the experimental weights.
2	part one was correct and the explanation in part two was correct but incomplete.
1	1) part one has an incomplete answer and part two is correct. 2) assertion of a false statement in part (b) even if part one is correct.
0	1) no answer 2) nonsense answer 3) no attempt to answer part two.

The following examples that fit the given scoring criteria were chosen from actual student papers.

Examples of Criterion 3 Responses

Response 1

part (a): choices a, b, f, g
part (b):
By knowing the weight of X in the compound and the weight of one atom of X, the number of X atoms could be determined. Similarly, the number of Y atoms could be determined by dividing the weight of Y in the compound by the weight of one Y atom.

Once the number of X and Y atoms in the compound are known, find out how many Y atoms there are for every X atom or vice versa.

Response 2

part (a):
part (b):
part 2: If you had the above information you would know how many X atoms there are to each Y atom and vice versa. If there were 2X atoms to each Y atom the formula would be X_2Y.

You could figure out the number of X atoms and Y atoms by dividing the weights of X&Y and dividing them by the weights of the atoms. You would then know the number of atoms there were of X&Y and could find the ratio of X atoms to Y atoms.

Examples of Criterion 2 Responses

Response 1

part a: a, b, e, f, g
part b:
Using the above information you take the weight of X - knowing the weight of one atom of X you can figure out how many X atoms are in the compound and the same for Y and thus derive some sort of formula for the compound.

Response 2

part a: a, b, f, g
part b:
If you know how much one atom of X weighs and know the total weight of X in the compound you'll know how many atoms of X there are. Same for Y.

Examples of Criterion 1 Responses

Since Criterion 1 deals with content misconceptions, examples of commonly occuring misconceptions will be given.

Response 1

part one: c, d, e,
part two:
The melting point is a characteristic of the compound and would tell some-

thing about it. The density of the compound is something that can't be changed no matter how much you have of that compound. The total weight of the compound does not change unless you add more to it. So these factors do not change and are important for determining the formula.

Response 2

part one: a, b, d, e
part two:
The weights of compounds X and Y would be necessary to determine the formula for the compound because if you knew both the individual weights of X and Y you could then add them together and compare the figure with the weight of the whole compound. If the figures were approximately equal you then would know that there wasn't another substance involved. But if the weights weren't equal then you would know there is another substance which you can't observe. The density of the compound would be very useful.

Response 3

part one: a, b, d
part two:
If you have the density of the compound you know the weight and volume of it, if it is written in terms of g/ml. Add the weights of the compounds together. Get the total weight of the compound. Use the density of the compound and the weight of the compound as a formula for the compound.

Response 4

part one: f, g
part two:
Because the formula of a compound or substance refers only for one molecule of the compound where appears just the two atoms representing each of the two elements that the compound is made of. In water there are only two elements and so in the formula appears with two atoms of the two elements H_2O.

Response 5

part one: c, d, e
part two:
You could combine this information and apply it to the Periodic Table of Elements. With the table you would be able to find information that matched the information you have obtained.

Examples of Criterion 0 Responses

Response 1

part one: a, b, d
part two:
I don't have any idea.

Response 2

part one: a, b, c, d, e

part two:
I have no idea but I suppose it would be helpful to find out all of these things and possibly identify the elements.

The second form of the CAT in learning cycle 5 was used as a post-test for the experiment. (see Appendix 5) The test consisted of three questions with each question being scored separately. The scoring criteria for question one was as follows.

CAT Form B Learning Cycle 5 Question 1

A score of ______ was assigned	if the answer to
3	1) part (a) was CH_2 and C_3H_6 **AND** part (b) explained that the ratio of the number of atoms is the same. 2) part (a) was CH_2 and C_3H_6 **AND** part (b) explained that the ratio of the weights of the atoms is the same. 3) part (a) didn't have any formula circled **AND** part (b) explained that each formula contained a different number of atoms.
2	If part (a) is wrong and part (b) is correct.
1	1) If part (a) is right and part (b) is incorrect. 2) If part (a) and part (b) are incorrect. 3) If part (a) is correct and there is not an answer to part (b).
0	1) no answer 2) nonsense answer

Example of student responses which fulfill the foregoing criteria follow.

Examples of Criterion 3 Responses

part (a): CH_2 and C_3H_6
part (b):
In CH_2 there are two hydrogen atoms for every carbon atom. In C_3H_6 the ratio of hydrogen to carbon atoms is 2 to 1 $\left(\frac{H6}{C3}\right)$.

The substances are composed of the same kinds of atoms in the same ratio.

part (a): CH_2 and C_3H_6
part (b):
The compounds CH_2 and C_3H_6 have the same ratio of the weight of carbon to the weight of hydrogen in the compound. Since none of the others have this same ratio, they could not be the same compound.

part (a): none
part (b):
None are the same because the amounts of atoms vary and some aren't even real compounds.

Examples of Criterion 2 Responses

part (a): H_3C and C_3H_6
part (b):
The ratio of elements of carbon and hydrogen are the same in both compounds.

part (a): C_6H_8 and C_3H_6
part (b):
The ratios of carbon atoms to hydrogen atoms are the same in both substances.

Examples of Criterion 1 Responses for Question 1

part (a): CH_2 and C_3H_6
part (b):
These two substances have the same atomic weights.

part (a): none
part (b):
None of them because for example CH_2 and C_3H_6 have the same molecular ratio, but the arrangement of their molecules differ and that makes them different.

part (a): CH, C_6H_8, H_3C, C_2H, CH_2, CH_4, C_3H_6
part (b):
Compounds can be made up of chemicals in different proportions and still be the same compound.

part (a): CH, C_6H_8, C_2H, CH_2, CH_4, C_3H_6
part (b):
These six compounds are all made up of carbon and hydrogen. Although they are arranged and put together differently, they should resemble each other and behave similarly.

part (a): H_3C and CH_4
part (b):
There is a certain amount of hydrogen in each of the substances but the carbon doesn't change.

The scoring criteria for question two of CAT Form B is listed below.

CAT Form B Learning Cycle 5 Question 2

A score of ______ was assigned	if the answer to
3	part (a) states that the atomic weights of nitrogen and chlorine are needed. **AND** part (b) compares the atomic weights of single atoms to the experimental weights of the substances.
2	1) If part (a) is incorrect and part (b) is correct. 2) If part (a) is correct and in part (b) the student realizes the need to find the ratio of atomic weights of single atoms.
1	if part (a) is correct and part (b) is incorrect.
0	blank or nonsense answer

The following examples that fulfill the scoring criteria were chosen from actual student responses.

Examples of Criterion 3 Responses for Question 2

Response 1

part (a):
The atomic weight of 1 nitrogen atom. The atomic weight of 1 chlorine atom.
part (b):
The formula of the compound must be a ratio such that the number of nitrogen atoms divided by the number of chlorine atoms is equal to the weight of the nitrogen divided by the weight of the chlorine.

Response 2

part (a):
The atomic weight of nitrogen and chlorine.

part (b):
With this information you can find a proportion. For instance, $\frac{5.1}{2.0} = \frac{\text{A of Cl}}{\text{A of N}}$. When the division of the first fraction equals the division of the second fraction it gives you the number of molecules of each substance. *A = atomic weight

Response 3

part (a):
The atomic weight of N and Cl.
part (b):
To determine the formula you must know the ratios of N atoms to Cl atoms (or vice versa). To do this find the ratio of the experiment's weights $\left(\frac{N}{Cl} = \frac{2g}{5.1g} = .4\right)$. Next you would have to determine ratios using atomic weights and find the one closest to .4. This would give you the formula of X atoms of N to Y atoms of Cl, thus = NxCly.

Examples of Criterion 2 Responses for Question 2

Response 1

part (a):
You need the atomic weights of the compounds.
part (b):
With the atomic weights, you can set up ratios of nitrogen to chlorine, and using the other information, compute the formula of the compound.

Response 2

part (a):
To determine the compound's formula the atomic weights of each element would also be needed.
part (b):
If one did not know the atomic weights, he wouldn't know the proportions for the formula, since all elements have a different weight.

Response 3

part (a):
The atomic weights of the substances. (Chlorine and nitrogen)
part (b):
If the atomic weights are found then division can be done to find a formula which would match up to Cl/N.

Examples of Criterion 1 Responses for Question 2

Response 1

part (a):
Atomic weight.
part (b):
blank

Response 2

part (a):
Atomic weight.
part (b):
The atomic weight will tell how much of the chemicals are contained in the compound.

Response 3

part (a):
Atomic weight.
part (b)"
Because without the atomic weight we can't find the formula.

CAT Form B Learning Cycle 5 Question 3

A score of ______ was assigned	if the anwer
3	1) The answer should include the problem set-up and the correct answer.
	2) The answer has the problem set up correctly but there are math errors.
2	1) The student attempts to use ratios using the correct information.
	2) The student uses ratio correctly for atomic weights but incorrectly for laboratory weights
1	1) The student's answer leaves information out.
	2) The student's answer uses improper information.
	3) The students answer uses correct information in non-ratio solution.
0	Non-solution

Examples of Criterion 3 Responses for Question 3

Response 1

$$\frac{\text{sulfur 5g}}{\text{oxygen 5g}} = 1$$

$$\frac{S}{O}\ \frac{32}{16} = 2 \qquad \frac{S}{O_2} = \frac{32}{32} = 1$$

$\therefore$ The formula for this compound is SO_2

Response 2

5.0 grams of sulfur
5.0 grams of oxygen

$$\frac{S}{O} = \frac{5.0}{5.0} = 1$$

atomic weight of sulfur = 32.0
atomic weight of oxygen = 16.0

$$\frac{S}{O} = \frac{32u}{16u} = 2 \qquad \frac{S}{O_2} = \frac{32u}{32u} = 1$$

Formula = SO_2

Examples of Criterion 2 Responses for Question 3

Response 1

$$\frac{\text{weight of sulfur}}{\text{weight of oxygen}} = \frac{5g}{5g} = 1$$

$$\frac{\text{Atomic weight of sulfur}}{\text{atomic weight of oxygen}} = \frac{32}{16} = \frac{2}{1}$$

Formula is S_2O

Response 2

$$\frac{\text{sulfur}}{\text{oxygen}} = \frac{5}{5} = \frac{S}{O} = \frac{32u}{16u}$$

$$S_5O_2 = \frac{5(32u)}{2(16u)} = 5$$

so S_5O_2 is the formula for this compound

Response 3

The compound has the same weight of each substance but the oxygen only weighs 1/2 of the weight of sulfur. Therefore there must be twice as much oxygen as sulfur.

$32/16 = 2 \qquad 32/32 = 1 \therefore = SO_2$

Examples of Criterion 1 Responses for Question 3

Response 1

$$\frac{S}{O} = \frac{32}{16} = \frac{5(32)}{5(16)} = \frac{160}{32} = 2$$

S_5O_5

Response 2

$$\begin{array}{ll} 5.0\text{g} & \text{S} \\ \underline{5.0\text{g}} & \underline{\text{O}} \\ 10.\text{g} & \text{SO} \end{array}$$

Carbon - C = 12.0

$$\frac{10\text{g}}{12\text{g}} = \frac{\text{SO}}{\text{C}} = .833$$

Response 3

$$\frac{5.0}{16.0} = .312$$

$$\frac{5.0}{32.0} = .156$$

Appendix 5D
BAR Written Comments

BAR Written Comments

LC- 5 CLASS 111 N = 22 , 22 with comments

Necessity, GE

	+	0	-	Comments
Lab	10		1	
Disc/Lecture	4		2	Should spend more time on class discussion after labs.
Demo				
Questions			3	
Problems	1			
Readings			2	
	15	0	8	23

	#	Comments
I'm Confused	2	
Activities Not Logical		
Too fast	2	
Too slow	2	
I Understand	4	
I Like	8	
I Don't Like		
Activities Are Logical		
	18	

Quotes: "The only thing I can think of is that things do seem to move rather fast. Many times I go on to the next Investigation or Reading without completely understanding the last one."

"I think that we should spend more time on class discussion after the labs to make sure that everything was understood. Or do more activities relating to the same subject."

5D-2

BAR Written Comments (cont.)

LC- 5 CLASS 111 N = 22 , 22 with comments

Necessity, GE

Quotes:

"It seems to me that the class could go a little faster by not having such long experiments before a topic or idea is discussed. The experiments take so much time that I would think that some of these ideas could be learned in a couple of days without the experiments."

BAR Written Comments

LC- 5 CLASS 114 N = 18 , 18 with comments

Necessity, GI_1

	+	0	-	Comments
Lab	14		1	Appreciated the time to understand lab.
Disc/Lecture	3		4	
Demo				
Questions		1	5	
Problems			4	
Readings				
	17	1	14	

	#	Comments
I'm Confused	5	
Activities Not Logical	1	
Too fast	2	
Too slow	2	
I Understand		
I Like	1	
I Don't Like		
Activities Are Logical	1	
	12	

Quotes:

5D-4

BAR Written Comments

LC- 5 CLASS 116 N = 24, 25 with comments

Necessity, GIE

	+	0	-	Comments
Lab	13		1	
Disc/Lecture	3		2	
Demo				
Questions			3	
Problems	6		4	
Readings	1		4	
	23	0	14	37

	#	Comments
I'm Confused	6	
Activities Not Logical	1	
Too fast	2	
Too slow	4	
I Understand	7	
I Like	5	
I Don't Like		
Activities Are Logical	1	
	26	

Quotes: "I think I learn a lot more in labs. You get to see things happen, then answer questions on it."

5D-5

BAR Written Comments

LC- 5 CLASS 122 N = 22 , 18 with comments

Necessity, GI_2

	+	0	-	Comments
Lab	12		1	
Disc/Lecture	1		1	Ties lab & questions.
Demo				
Questions			3	
Problems			1	
Readings				
	13	0	6	19

	#	Comments
I'm Confused	4	
Activities Not Logical		
Too fast	3	
Too slow	3	
I Understand		
I Like	2	
I Don't Like	1	
Activities Are Logical		
	13	

Quotes: "I like best the class discussions because it ties together the lab and questions, also gives me a chance to ask any unanswered questions about lab or discussion taking place."

"I like the labs the most because you get to observe and watch what is being studied. It's always fun to make observations and see new things."

BAR Written Comments

LC- 5 CLASS 125 N = 25 , 17 with comments

Necessity, IE

	+	0	-	Comments
Lab	4		1	Likes lab followed by discussion.
Disc/Lecture	4			
Demo				
Questions				
Problems	4		3	Likes doing problems during class when help is available.
Readings			1	
	12	0	5	17

	#	Comments
I'm Confused	5	
Activities Not Logical		
Too fast	2	
Too slow		
I Understand	1	
I Like	4	
I Don't Like	1	
Activities Are Logical	1	
	14	

Quotes: "I can't seem to retain anything we have learned. I think we move from one thing to the next at a very rapid pace."

"I like doing the labs and then discussing what you found and why you found it. As opposed to Mid-High when they just made you do a lot of labs without ever discussing what you found or should have found. Sometimes I can do a lab and not be aware of what is really happening..."

"I like how the activities are organized, but I do get confused."

6

Appendix 6A
Student Materials for LC-7

INVESTIGATION 7

Name____________________

Section____________________

GATHERING DATA
LEAD NITRATE AND POTASSIUM IODIDE

A. Weigh 3.31 g of lead nitrate--$Pb(NO_3)_2$--into a clean, dry weighing cup. Transfer this solid to your clean 50 ml beaker. Add 25 ml of distilled water to the beaker and stir with your stirring rod until the solid is completely dissolved. Rinse off the stirring rod into the beaker.

B. Weigh 3.32 g of potassium iodide--KI--into a clean, dry weighing cup. Transfer this solid to your clean 100 ml beaker. Add 25 ml of distilled water to the beaker and stir with your stirring rod until the solid is completely dissolved. Rinse off the stirring rod into the beaker.

C. Pour the $Pb(NO_3)_2$ solution into the KI solution. Rinse the 50 ml beaker into the 100 ml beaker, using your wash bottle.

D. Stir the mixture in your 100 ml beaker. Describe the results. Specify any evidence for a chemical change.

E. Weigh your clean, dry 400 ml beaker to two decimal places.

____

____

____

average ____________________

F. Weigh a piece of filter paper to two decimal places.

____

____

____

average ____________________

G. Set up your funnel on a ring stand. Place your 400 ml beaker under the funnel to catch the filtrate, fold a filter paper and place it in the funnel, and then filter the mixture from the 100 ml beaker. Rinse any remaining residue from your 100 ml beaker into the filter, using your wash bottle.

H. When all the filtrate has passed through the filter, rinse the residue with distilled water from your wash bottle. Allow this rinse water to collect in your 400 ml beaker also.

I. Remove the filter paper and residue from the funnel and carefully place them on a clean watch glass. NOTE: BE CAREFUL NOT TO LOSE ANY OF THE RESIDUE.

J. Put the watch glass with the filter paper and residue in the place designated by your teacher.

K. Label your 400 ml beaker, containing the filtrate, and put it in the place designated by your teacher.

L. When the filter paper and residue are dry, weigh them to two decimal places.

____

____

____

average ____________________

M. Compute the weight of the residue. Show your calculations.

N. When your 400 ml beaker has been returned to you, weigh the system to two decimal places.

____

____

____

average ____________________

O. Record observations of the beaker's contents. Compute the weight of the substance contained in the beaker. Show your calculations.

P. Record your data on the first line of the table and fill in the class data on the remaining lines.

Weight of residue	Weight of filtrate	% Weight Change

THE IDEA
QUESTIONS

Name____________________
Section____________________

1. State the evidence that a chemical change has occurred in this interaction.

2. List the formulas for the ions present in the lead nitrate -- $Pb(NO_3)_2$ -- and potassium iodide -- KI -- systems before you mixed them.

3. List the formulas for the ions present after you mix the lead nitrate with the potassium iodide.

4. What change has occurred with the ions to explain the chemical change you noticed when you mixed lead nitrate and potassium iodide?

5. Write a chemical equation to represent the reaction studied in this investigation.

6. Compare the weights of the reactants with the weights of the products. What does this comparison illustrate about chemical reactions.

EXPANDING THE IDEA
ION EXCHANGE REACTIONS

Name____________________
Section___________________

A. At your laboratory station you will find a set of six substances in labeled dropper bottles. Name each of the substances and identify the ions present.

	Formula	Name	Ions
1.			
2.			
3.			
4.			
5.			
6.			

B. In the following procedures be careful not to contaminate the substances in the dropper bottles, (Only use the dropper provided with each bottle, don't use the dropper to stir mixtures, don't allow the tip of the dropper to touch the mixtures). Into a small distilled water rinsed test tube put a few drops of substance #1. Add a few drops of substance #2 and mix by agitating the test tube. Observe the mixture for any evidence of a chemical reaction.

C. Making sure the test tubes you use are thoroughly clean and rinsed with distilled water, combine each of the six substances with the other five until you have tried all of the possible pairs. Enter your data in the following chart by indicating any evidence of chemical reaction you observe. Write NR (for no reaction) for any combination(s) which show no evidence of reaction.

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

QUESTIONS

1. For each combination of substances which results in a precipitate write a balanced chemical equation.

2. For the reactions in Question #1 identify the product(s) precipitated. Eliminate other responsibilities by examining the reactions which didn't result in a precipitate. Briefly state the logic used to identify each precipitate.

EXPANDING THE IDEA
READING 7
PREDICTING THE PROPER PRODUCTS

Name____________________
Section____________________

In investigation 7 and in earlier investigations you were asked to predict the products of chemical reactions and then to write equations representing those reactions. In most cases you did this by writing the formulas for the reactants on the left side of an equation and then proposed possible products using evidence that new materials were formed, and used logic to account for any remaining substances.

Several kinds of evidence can be used to indicate that a chemical reaction has taken place. All of these kinds of evidence indicate that a different substance exists after the reaction than before. A change in the physical properties of substances can also indicate that a chemical reaction has taken place although it is not always easy to distinguish between a physical and a chemical change.

Specific products of chemical reactions can also be identified by their chemical and/or physical properties. Following is a discussion of some examples of chemical reaction indicators.

1. Formation of a gas - In Investigation 2, calcium was mixed with water. Bubbles were observed forming in the water. The gas was tested and found to be hydrogen gas. The reaction was: $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$. Following is a key to identifying some common gases.

Name	Formula	Color	Odor	Combustion	Mixes with Water	Specific Test
Hydrogen	H_2	none	none	burns	no	burn explosively
Oxygen	O_2	none	none	supports burning	no	glowing splint flames
Carbon Dioxide	CO_2	none	none	no	yes	turns lime water milky
Nitrogen Dioxide	NO_2	brown	choking	--	yes	mixed with water turns litmus red
Bromine	Br_2	brown	choking	--	yes	liquid at room temperature
Chlorine	Cl_2	pale green	choking	--	yes	forms yellow mixture with water
Ammonia	NH_3	none	smelling salts	--	yes	mixed with water turns litmus blue
Sulfur Dioxide	SO_2	none	suffocating	--	yes	mixed with water turns litmus red
Hydrogen Sulfide	H_2S	none	rotten eggs	--	yes	--
Hydrogen Chloride	HCl	none	choking	--	yes	mixed with water turns litmus red
Water Vapor	H_2O	none	none	--	--	colbalt chloride paper turns pink

2. Color Change - During Investigation 2, a reaction between ammonium hydroxide and copper sulfate was carried out. Upon mixing, the substance turned from a pale blue to an intense blue. The color change indicates the formation of a new substance. The reaction is:

$$4NH_4OH + \underset{\text{(light blue)}}{CuSO_4} \longrightarrow \underset{\text{(dark blue)}}{CuSO_4(NH_3)_4} + 4H_2O.$$

Many elements and ions are colored substances that change these colors when put in combination with different substances. Examples of such materials are the ions of elements from the middle (B column elements) of the periodic table (Cr, Mn, Fe, Co, Ni, and Cu ions). Cu ions in compounds like $CuSO_4(H_2O)_5$, $Cu(NO_3)_2$, and $CuCl_2$ are light blue or green. Co ions are red in $CoCl_2(H_2O)_6$ and blue in $CoCl_2$. Mn ions are purple in $KMnO_4$ and black in MnO_2.

3. Formation of a precipitate — In Investigation 7 lead nitrate and potassium iodide were mixed resulting in a substance which would not mix with water and thus precipitated. The precipitate was identified as lead iodide. The overall reaction was:

$$Pb(NO_3)_2 + 2KI \longrightarrow \underset{\binom{\text{yellow}}{\text{solid}}}{PbI_2} + 2KNO_3.$$

As you gain experience with chemical systems, you will begin to recognize classes of compounds which mix with water and other classes which will not mix with water. Meanwhile you will either have to rely on your memory or records to identify substances which will not mix with water.

4. A change in weight -- In Investigation five hydrated copper (II) sulfate was heated. The color of the solid faded from blue to white. Also the weight of the residue was less than the weight of the reactant. The reaction was:

$$\underset{\text{(blue)}}{CuSO_4(H_2O)_5(s)} \longrightarrow \underset{\text{(white)}}{CuSO_4(s)} + 5H_2O(g).$$

In this reaction the change in weight is only one indication that a chemical reaction has taken place; there is also a color change and the evolution of a gas (H_2O vapor). However, sometimes a weight change is the only obvious indication of a chemical reaction. For example, heating white powdered hydrated barium chloride results in a white powder. However, the weight decreases. The reaction is:

$$\underset{\substack{\text{(white)}\\ 2.44g}}{BaCl_2(H_2O)_2(s)} \longrightarrow \underset{\substack{\text{(white)}\\ 2.08g}}{BaCl_2(s)} + 2H_2O(g).$$

Of course, the total weight of the reactants should be equal to the weight of the products. However, since the balance of the weight (2.44g - 2.08g = .36g) is carried off as water vapor it is not weighed.

By using the above indicators, and other pieces of evidence (litmus test, conductivity, melting and boiling points and density measurements) you can make reasonable predictions concerning the products of a chemical reaction you might be studying in the laboratory. However, some products do not give any direct observation of their presence. They must be deduced indirectly. One of the most powerful methods of determining these products is to take advantage of the idea that "chemical reaction involve the rearrangement of atoms." Because of this, there must be the same number and kind of atoms before a chemical reaction as there are after. By a process of elimination you can often propose a complete set of products. For example, if you were to strongly heat potassium chlorate ($KClO_3$) a white residue results and a gas which flames a glowing splint is given off. The gas must be oxygen and you could write an equation:

$$KClO_3(s) \xrightarrow{\Delta} \underset{\text{residue}}{\text{white}} + O_2(g)$$

In support of this proposal the weight of the residue is less than the weight of reactant. The equation as written doesn't account for the K and Cl atoms. You might be tempted to write the compound KClO as the residue since you will then account for all of the atoms you started with.

$$KClO_3(s) \xrightarrow{\Delta} KClO(s) + O_2(g)$$

You can test your hypothesis that the residue is KClO by measuring the melting point of the residue and looking up the melting point of KClO in a reference such as the Merck Index or the Handbook of Chemistry and Physics. The residue melts at 776°C. However, according to the Handbook of Chemistry and Physics, KClO decomposes when heated. Another possible compound which will account for K and Cl is KCl. The reaction would be:

$$KClO_3(s) \longrightarrow KCl(s) + O_2(g).$$

KCl melts at 776°C and consequently is probably the residue. However, although the equation above accounts for the "kinds" of atoms it does not account for the "number". This requires balancing the equation by adjusting the coefficients.

$$2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g).$$

The above reaction is called a decomposition reaction. Often recognizing types of reactions can aide in identifying possible products. A decomposition reaction starts with a single reactant which is divided into two or more products. A synthesis reaction does the opposite. Two or more reactants are combined to form a single product. In investigation five, the heating of magnesium is an example of a synthesis reaction.

$$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$$

The reaction of Investigation seven is:

$$Pb(NO_3)_2 + 2KI \longrightarrow PbI_2 + 2KNO_3.$$

The lead and potassium ions "trade places" to form the products. This kind of reaction is called a double displacement reaction. Another possible type of reaction involves a "single displacement". Oddly enough these are called single displacement reactions. Al displaces hydrogen in this example from Investigation two:

$$2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2.$$

As a summary, the following are steps to writing equations for reactions being studied in the laboratory.

1. Write correct formulas for the reactant and/or products you know exist.
2. Use chemical or physical evidence to infer other reactants or products. Write correct formulas for these.

3. Use logic to account for remaining atoms by proposing likely substances. Write correct formulas for these.
4. Balance the equation by adjusting the coefficients.

READING 7
QUESTIONS

Name____________________
Section__________________

Predict the products and write balance equations for each of the following reactions.

1. Copper metal reacts with nitric acid (HNO_3) to produce a blue solution and a brown choking gas.

2. Magnesium metal reacts with hydrochloric acid (HCl) to produce a gas which burns explosively.

3. Lead acetate in water reacts with sodium iodide in water to produce a yellow precipitate. When the remaining liquid is boiled away a white solid remains.

4. Silver nitrate in water reacts with potassium chromate in water to produce a red/brown precipitate.

5. Lead metal reacts with sulfuric acid (H_2SO_4) to produce a white solid precipitate and a suffocating choking gas.

6. When sulfur is heated a suffocating choking gas results.

7. Iron (II) sulfide reacts with sulfuric acid to produce a gas which smells like rotten eggs.

INVESTIGATION 7

GATHERING DATA - READING
LEAD NITRATE AND POTASSIUM IODIDE

Lead nitrate and potassium iodide are white, crystalline solids. If 3.31g of lead nitrate - $Pb(NO_3)_2$ - are mixed with distilled water, a colorless solution is formed. A colorless solution also forms when 3.32g of potassium iodide -KI- are mixed with distilled water. The $Pb(NO_3)_2$ solution is poured into the KI solution. The mixture is stirred and observed for evidence of a chemical change. The two solutions were colorless and the resulting mixture is yellow. There is a precipitate formed.

A funnel is set on a ring stand and a weighed 400 ml beaker placed under the funnel to catch the filtrate. The filter paper is weighed and placed in the funnel. The mixture is then filtered. When all the filtrate has passed through the filter, the residue is rinsed with distilled water.

The filter paper with the residue and beaker with the filtrate are dried. The following weights were obtained.

weight of residue	4.35g
weight of dried filtrate	2.09g

Although the filtrate was a colorless liquid, it left white substance in the beaker when it was dried. The residue on the filter paper is a yellow solid.

The percentage weight change in the system can be obtained by dividing the difference in the weight of the products and reactants by the weight of the reactants. For the system in this reading:

$$\text{Percentage Weight Change} = \frac{6.44g - 6.63g}{6.63g} \times 100$$

$$= \frac{-.19g}{6.63g} \times 100$$

$$= -2.86\%$$

Three other groups performed the experiment and obtained the following data.

Weight Data (in grams)

	Group 2	Group 3	Group 4
Beaker and dried filtrate	150.54	149.36	143.91
Beaker	148.43	147.23	141.84
Filtrate	2.11	2.13	2.07
Filter paper and residue	6.96	5.79	5.76
Filter paper	2.55	1.33	1.28
Residue	4.41	4.46	4.48

Investigation 7
THE IDEA - Reading

The mixture of solutions of lead nitrate with potassium iodide, which was discussed earlier, results in a chemical reaction. A chemical reaction is evidenced by the change in color (colorless to yellow) and by the formation of a precipitate (a substance that is insoluble in the reaction medium). The products of this reaction can be deduced by examining the formulas for the reactants:

$$Pb(NO_3)_2 + KI.$$

Notice that lead nitrate is made up of the lead (2+) ion and the nitrate (1-) ion, whereas the potassium iodide is composed of the potassium (1+) ion and the iodide (1-) ion. It would be impossible for our products to be combinations of lead with potassium or iodide with nitrate because these combinations would require ions of like charge to come together. We know, from our work with electrical charges, that like charges repel. It is also unreasonable to assume that the products are the same as the reactants because that would mean that no chemical change had occurred. The logical choice for products, then would be potassium nitrate (KNO_3) and lead iodide (PbI_2). This can be partially summarized by the following relationship:

$$Pb(NO_3)_2 + KI \longrightarrow PbI_2 + KNO_3.$$

You will observe that the left-hand side of the relationship shows two nitrate ions and one iodide ion, while the right-hand side shows two iodide ions and only one nitrate. This problem can be resolved if we specify that two molecules of KI will be required to react with one molecule of $Pb(NO_3)_2$, producing one molecule of PbI_2 and two molecules of KNO_3. In equation form, this would be

$$Pb(NO_3)_2 + 2KI \longrightarrow PbI_2 + 2KNO_3.$$

This procedure, called "balancing an equation", is made necessary in order to account for neutral compounds forming from the ions available to the system.

The data array given earlier for the product weights shows that the residue weighed over twice as much as the filtrate. If we obtain table weights for the elements in the product compounds, we get the following information:

$$PbI_2 = 207 + 127 + 127 = 461$$

$$KNO_3 = 39 + 14 + 16 + 16 + 16 = 101.$$

Since lead iodide has a higher molecular weight than potassium nitrate, we could expect the heavier weight to be associated with PbI_2. Looking at the balanced equation, one can see that two potassium nitrate molecules will be produced for each lead iodide molecule. Such a doubling of the potassium nitrate weight will give us the proportions of weights that we observe in the data array.

The change in weight between reactants and products is, for all practical purposes, zero. That is, there is no matter created or destroyed by the chemical reaction, and we say that weight has been conserved. This principle of conservation of weight can be applied to any chemical reaction.

One other point should be made concerning this reaction. If you look at the balanced equation, you will see that (in going from left to right) one could imagine that lead is pushing potassium out of the way and taking its place with iodine. At the same time, potassium could be seen to be displacing lead and taking its place with nitrate. It is for this reason that the reaction is referred to as a "double displacement" reaction or as an "ion exchange" reaction. Notice that this reaction also illustrates another principle that can be generalized. That principle is that chemical reactions involve changes in the combinations of atoms.

Expanding the Idea
Reading 7a
Precipitation Reactions

Chemical substances like NaCl (sodium Chloride) are bonded together by ionic bonding. NaCl can react with other chemical substances like $AgNO_3$ (silver nitrate). However, in the solid form it is impossible for the individual reacting particles to come in contact with each other to form new substances. However, if these materials are dissolved in water the individual reacting particles can come in contact and reactions are possible. For example, NaCl might be dissolved in a sample of water, $AgNO_3$ dissolved in a second sample of water, and then the two solutions combined.

With ionic substances like NaCl and $AgNO_3$ a type of reaction, called a double displacement reaction, occurs. The mechanism involves the replacement of one positive ion with the other with the simultaneous replacement of the second with the first. This might be more clear with a diagram.

$$\begin{tikzcd}
NaCl \arrow[r, bend right] & AgNO_3 \arrow[l, bend right]
\end{tikzcd}$$

The overall reaction is represented by the equation:

$$NaCl + AgNO_3 \longrightarrow NaNO_3 + AgCl$$

Many chemical reactions form products which are in a different phase than the reactants. Occasionally the mixing of solutions in a double displacement reaction results in a substance which does not dissolve in water. This insoluble material will separate from the solution forming a solid which will eventually settle to the bottom of the container used. This solid is called a precipitate. The process of forming the precipitate is called precipitation. In the double displacement reaction between solutions of NaCl and $AgNO_3$ a white precipitate is formed. What is the precipitate?

In this reaction there are only a few possibilities. The precipitate could be one of the products ($NaNO_3$ or AgCl), or it could be both of the products. That is, $NaNO_3$ is insoluble in water, AgCl is insoluble in water, or both $NaNO_3$ and AgCl are insoluble in water. In order to identify the precipitate, more information is needed. You might obtain samples of $NaNO_3$ and AgCl and try to dissolve them in water. You might try other combinations of ionic solids which would produce $NaNO_3$ but not AgCl or vise versa. If a precipitate did not form you would know the identity of the precipitate by a process of elimination.

Consider the following reactants and results when solutions of ionic solids are mixed:

(1) $FeCl_3 + KOH \longrightarrow$ Precipitate

(2) $FeCl_3 + NaOH \longrightarrow$ Precipitate

(3) $FeCl_3 + NaNO_3 \longrightarrow$ No Precipitate.

Writing balanced equations for these double displacement reactions results in the following:

(1) $FeCl_3 + 3KOH \longrightarrow Fe(OH)_3 + 3KCl$

(2) $FeCl_3 + 3NaOH \longrightarrow Fe(OH)_3 + 3NaCl$

(3) $FeCl_3 + NaNO_3 \longrightarrow Fe(NO_3)_3 + 3NaCl$.

In equation two either $Fe(OH)_3$ or NaCl must be insoluble to account for the precipitate which was formed. Since NaCl was formed in equation three and no precipitate formed, then NaCl must not be a precipitate in equation two either. The precipitate of equation two must be $Fe(OH)_3$. If $Fe(OH)_3$ is a precipitate in equation two then it certainly must be also precipitate in equation one. However, since we have no evidence to eliminate KCl then the precipitate of equation one must be either $Fe(OH)_3$ or $Fe(OH)_3$ and KCl. We would need more information before we could eliminate KCl.

Appendix 6B

Teacher Materials for LC-7

Investigation 7

Invention Discussion Outline (Control)

A. Ask if the mixture of the two solutions resulted in a chemical change. Require supporting evidence from observations.

   1. Have students identify the reactants by name and formula.

   2. Establish that there would have to be a limited number of product possibilities, and then ask the students to supply product possibilities.

      a. Eliminate reactant recombination as a possibility.

      b. Eliminate combinations of negative ions with each other and of positive ions with each other.

   3. When products have been specified, lead the class through balancing the equation. This can be done by showing the need to conserve ions in order to arrive at charge balanced formulas.

   4. Lead a discussion to identify the products. This will involve looking at the product weight data. Using product formulas and atomic weights, students should ultimately be able to conclude that the heavier of the two products is lead iodide. That this product is the yellow precipitate can be elicited from the class.

B. Ask the students to examine the percentage weight change column of their weight data tables. These percentage weight changes, between total reactant weight and total product weight, should approximate 0% change. The idea that weight is conserved in chemical reactions can then be stated to summarize the discussion of this information.

C. Ask the students to state what changes had to occur in going from reactants to products in this reaction. (The ions "changed partners" or rearranged to form products.)

   1. Make the invention statement: "chemical reactions involve changes in the combination of atoms."

   2. Lead the class through the perspective of imagining that displacement of positive and negative ions occurs during the reaction giving rise to the name "double displacement" reaction, or "ion exchange" reaction.

Expanding the Data for LC7 - Lesson Control Form

Control Group

Have students do "ion exchange reactions" lab (I7-6, 7).
 Use set 3 from teacher notes as reaction set

Have students answer questions at end of lab. If they have trouble organize them into small groups.

Have class discussion to compare results:

(1) Develop equations for reactions which make precipitates. Make a table of these reactions.

(2) Make a table of reactions which do not form precipitates. Make the point that although no visible reaction takes place it is still possible that these reactions take place.

(3) Identify the precipitate in each reaction by using the logic that "if it precipitates in one reaction it will precipitate in all. Eliminate non precipitators from the "no precipitate" reaction table. You will not be able to eliminate KCl from the evidence of this experiment. Make this point and ask how you might eliminate KCl. See reading 7a for the coverage of this discussion. (You will not use this reading in the control group.)

Have students do reading 7 and answer questions.

Have group and class discussion on questions.

Form Experiment - Change of Lesson Control
Investigation 7

Teacher 1

(Teacher presents data array with explanation)

A. Lead nitrate = $Pb(NO_3)_2$ - is a white, crystalline solid. When distilled water was added to 3.31g of lead nitrate, a colorless solution was formed.

B. Potassium iodide - KI - is a white, crystalline solid. When distilled water was added to 3.32g of potassium iodide, a colorless solution was formed.

C. When the $Pb(NO_3)_2$ solution and the KI solution were mixed, there was a color change and precipitate formed.

D. The mixture from section C was filtered and a yellow residue and the filtrate were dried.

E. The data array which follows was obtained by performing the procedures outlined above.

Weight Data (in grams)

	Group 1	Group 2	Group 3	Group 4
beaker and filtrate	154.54	150.54	149.36	143.91
beaker	152.45	148.43	147.23	141.84
dried filtrate	2.09	2.11	2.13	2.07
filter and residue	5.59	6.96	5.79	5.76
filter paper	1.24	2.55	1.33	1.28
residue	4.35	4.41	4.46	4.48

F. The percentage weight change is calculated by dividing the differences in the weight of the products and reactants by the weight of the reactants and multiplying by 100.

$$\text{Percentage Weight Change} = \frac{\text{Weight of Products} - \text{Weight of Reactants}}{\text{Weight of reactants}} \times 100.$$

System #1 % Weight Change

$$= \frac{6.44g - 6.63g}{6.63g} \times 100$$

$$= \frac{-.19g}{6.63g} \times 100 = -2.86\%$$

System #2 % Weight Change

$$= \frac{6.52g - 6.63g}{6.63g} \times 100$$

$$= -1.70\%$$

System #3
% Weight Change $= \frac{6.59g - 6.63g}{6.63g} \times 100$

$= -.6\%$

System #4
% Weight Change $= \frac{6.55g - 6.63g}{6.63g} \times 100$

$= -1.2\%$

Investigation 7
Invention Lecture (Teacher 1 and 2)

A. Point out that the mixture of the two solutions -- $Pb(NO_3)_2$ and KI -- resulted in a chemical reaction. This is evidenced by the color change and the information of a precipitate.

   1. With reactant formulas on the board, go through the various product "possibilities", rejecting like-charged ion pairs and reactant recombination on the proper logical grounds, and concluding that the products must be PbI_2 and KNO_3.

   2. Proceed to balance the equation and explain the need for doing so (i.e., the need for conserving ions in order to arrive at charge balanced formulas).

   3. Identify the yellow, insoluble substance (described in the data presentation or the reaction demonstration) as lead iodide. Prove this by arguing from formula weights (461 for PbI_2 and 101 for KNO_3) and the weight data in the data array.

B. Point out the approximation to 0% weight change in the percentage weight change column. Tell the class that this shows that matter is neither created nor destroyed in a chemical reaction; that weight is conserved.

C. Show how the reaction can be presumed to occur by pairs of ion displacements (Pb^{2+} displaces K^+, while K^+ displaces Pb^{2+}) so that this reaction is called a "double displacement" reaction or an "ion exchange" reaction.

D. Conclude the lecture by stating that this reaction shows that "chemical reactions involve changes in the combination of atoms".

Expanding the Data for LC7 - Lesson Control Form

Teacher 1 (Lecture)

Teacher presents data array (6B-7) on overhead or blackboard and briefly describes how data was generated:

(1) "Samples of six solutions were mixed together in every possible pair. That is, solution one was mixed with solution two, three, four, five, and six. Then solution two was mixed with solution three, four, five, and six. This was done until all possible combinations were done. In some cases no visible reaction took place. In six cases, however, precipitates were formed.

Teacher generated double displacement equations for all of the reactions which develop precipitates. On a separate table generate those reactions which do not result in a precipitate. Use the logic in reading 7a to identify what the precipitate is.

Teacher lectures about reactions using reading 7 as a base.

(1) Summarize the various kinds of evidence which can be used to indicate that a chemical reaction has taken place, and how this evidence can be used to predict the products of a reaction. Provide a copy of the chart on page R7-1. Use the examples from the reading.

(2) Discuss using indirect information to predict non-visible products. Again use reading 7 examples.

(3) Discuss reaction types and how that might be used to determine products.

(4) Summarize

Teacher assigns questions (R7-5, R7-6).

Teacher goes through and explains assigned questions.

	6 $NaNO_3$	5 KOH	4 NaOH	3 $CoCl_2$	2 $Co(NO_3)_2$	1 $FeCl_3$
1. $FeCl_3$	--	ppt	ppt	--	--	X
2. $Co(NO_3)_2$	--	ppt	ppt	--	X	X
3. $CoCl_2$	--	ppt	ppt	X	X	X
4. NaOH	--	--	X	X	X	X
5. KOH	--	X	X	X	X	X
6. $NaNO_3$	X	X	X	X	X	X

Form Experiment - Change of Lesson Control
Investigation 7

Teacher 2
(Teacher demonstration with explanation)

A. Before class begins weigh the samples of lead nitrate and potassium iodide.

$Pb(NO_3)_2$ - 3.31g
KI - 3.32g

B. Perform the activities outlined in sections A through D of the student investigation. Emphasize to the students that the samples of $Pb(NO_3)_2$ and KI are pre-weighed.

C. Describe the results of pouring (the $Pb(NO_3)_2$ solution into the KI solution.

D. Set up a demonstration model of the filtering apparatus. Describe the procedure as outlined in section E through K.

E. Then explain that due to the time involved in the filtering and drying processes, the following data will be presented as the results obtained by four groups of students. Stress that the procedure used to obtain these data was the same as we have begun here.

Weight Data (in grams)

	Group 1	Group 2	Group 3	Group 4
Beaker and dried filtrate	154.54	150.54	149.36	143.91
Beaker	152.45	148.43	147.23	141.84
Filter paper and residue	5.59	6.96	5.79	5.76
Filter Paper	1.24	2.55	1.33	1.28

F. To compute the weight of the residue we subtract the weight of the filter paper from the filter paper and residue.

Weight of filter paper and residue ____________________
Weight of filter paper ____________________
Weight of residue ____________________

G. To compute the weight of the filtrate you follow the same procedure.

Weight of beaker and filtrate ____________________
Weight of beaker ____________________
Weight of filtrate ____________________

H. Now we need to find the percentage weight change in the system. To do this we divide the difference in the weight of the products and reactants by the weight of the reactants.

$$\text{Percentage Weight Change} = \frac{\text{Final weight} - \text{initial weight}}{\text{initial weight}} \times 100$$

Expanding the Idea for LC7 - Lesson Control Form

Teacher 2 (Demo)

Teacher presents a blank data array like 6B-7 (see below) and displays bottles of stock solutions of six compounds (set 3).

Using six 50 ml beakers on the overhead, the teacher adds and labels each beaker with the six solutions. Then solution six is added to each of the beakers. The point is made that solution six need not be added to itself. The table is modified for the other examples where a compound is added to itself. Solution five is then added to each of the other five. It is announced that adding five to six is redundant and redundancies are eliminated from the chart.

The teacher fills in the result of each test on the table and then discusses them as was done for Teacher 1.

The teacher then lectures (as in Teacher 1) about the material in reading 7, demonstrating qualitatively as many of the reactions which can conveniently and quickly be done.

	6	5	4	3	2	1
1						
2						
3						
4						
5						
6						

Expanding the Idea for [illegible]C7 - Lesson Control Form

Reading

Teacher hands out 7a and asks the students to read it. Teacher offers to answer any questions students have, and answers them directly.

Teacher hands out 7 and asks the students to read it. Teacher offers to answer any questions.

Teacher assigns questions as seat work and offers to answer questions during seat work.

Teacher collects papers, grades them with feed back questions and returns them for correction.

Appendix 6C
CAT Tests for LC-7

Name ____________________
Section ____________________
Date ____________________
Code ____ LC7- ____________

1. Assume that $CuSO_4$ + $Al(NO_3)_3$ + NH_4Cl will freely react with each other in pairs. In the following list of compounds, circle the ones that could possibly form.

$Cu(NO_3)_2$
$Al(NH_4)_3$
NH_4Cl
SO_4Cl_2
$Al(NO_3)_3$

$CuCl_2$
$(NO_3)_2SO_4$
$Al_2(SO_4)_3$
NH_4NO_3
Cu_3Al_2

$(NH_4)_2Cu$
Cl_2SO_4
$(NH_4)_2SO_4$
$CuSO_4$
$AlCl_3$

Choose any three of the compounds that could not form, and explain why they could not form.

Name____________________
Section__________________
Date____________________
Code_______LC7-________

1. Four elements will be designated by the letters X, Y, Z, and Q.

X will form positive ions
Y will form negative ions
Z will form positive ions
Q will form negative ions

Analyze each of the following relationships. Indicate whether the reaction is possible. If the reaction is not possible, explain why it is impossible.

a. $XZ + YQ \longrightarrow ZY + XQ$ possible/impossible

explanation:

b. $X + Z \longrightarrow XZ$ possible/impossible

explanation:

c. $QX + ZY \longrightarrow ZQ + YX$ possible/impossible

explanation:

d. $YZ \longrightarrow ZY$ possible/impossible

explanation:

e. $Z + XQ \longrightarrow X + ZQ$ possible/impossible

explanation:

f. $XY \longrightarrow X + Y$ possible/impossible

explanation:

2. Compound A is heated with Compound H in a beaker. After the chemical reaction an exact analysis showed Compound R and Compound D. Consider the following weight data and offer an explanation for the weight data.

Compounds	Weights
A	4g
H	3g
R	5g
D	1g

Description, Rationale, and Grading Criteria for LC-7 CATs

The concept invented during the work in this learning cycle is: "Chemical reactions involve changes in the combinations of atoms" This rather limited definition has, as its basis, the extensive prior experience of the students with chemical systems and the determination of chemical change in those systems using observational criteria (e.g., color, change, precipitation, gas production, etc.). The invention is also based on a recently-discussed model of the attraction of oppositely-charged ions to form compounds. Another important aspect of this learning cycle, although it is not the central concept, is the prediction of reaction products on the basis of observational information and reasonableness of ionic combinations. The final important conceptual aspect of this learning cycle is the direct application of the law of conservation of mass to an experimental system.

Two CAT tests were developed for this learning cycle. The pre-learning cycle test consisted of one question used to determine a student's understanding of how to combine ions to obtain reasonable products from a given set of reactants. Success in answering the question would also necessarily be a function of the student's ability to recognize the formulas for common ions and to recall the generic charge on those ions. The post-learning cycle test dealt with this same issue, of predicting products and combining ions, in a generalized way. The post test also contained a question that dealt specifically with the conservation of mass principle. These tests were scored in accordance with the general scale discussed in Chapter two of this report.

Pre-Learning Cycle CAT

This CAT had only one question that was scored, but the grading scale was based on the combination of answers from the first and second parts of the question. According to the information given in the question, there were six possible choices for products of the reactions: $Cu(NO_3)_2$, $CuCl_2$, $Al_2(SO_4)_3$, NH_4NO_3, $(NH_4)_2SO_4$, and $AlCl_3$. The second part of the question asks the students to offer explanations about some of the compounds (or ion combinations) that could not reasonably form within the parameters of the question.

The following is a presentation of the scoring criteria for the Pre-learning cycle test with example responses following the statement of a criterion.

Criterion 3

> The student must circle only the six correct formulas, choose three incorrect formulas and explain them in terms of (a) like-charged ions repel or (b) reactant molecules on the product side of the equation indicates that no reaction occurred.

Example Response

> (all six compounds were circled); "$CuSO_4$, $Al(NO_3)_3$, NH_4Cl. They are already formed."

Criterion 2

> (1) All of the formulas circled are correct but not all six are circled. (NOTE: The minimum number of formulas circled, to satisfy this criterion, is three, and the minimum number discussed in the second part is one formula.)
>
> (2) The reactant molecules are the ones circled in the first part, and the second part is correctly done or correct to the extent that it is done but incomplete.

Example Response

> (circled the reactant formulas and all six product formulas) "$Al(NH_4)_3$ cannot form because both aluminum and ammonium have positive charges; $(NO_3)_2SO_4$ cannot form because both NO_3 and SO_4 have negative charges; CL_2SO_4 cannot form because both Cl and SO_4 have negative charges."

Criterion 1

> (1) Inclusion of incorrect formulas in response to either part of the question; or (2) a criterion 2 or criterion 3 response to the first part with an incorrect explanation in the second part.

Example Response

> (circled $CuCl_2$ and $AlCl_3$) "Cu_3Al_2 could not form because they are both positive ions; $Cu(NO_3)_2$ could not form because they are both positive

ions; $Cu(NO_3)_2$ could not form because they are both positive ions; NH_4Cl could not form because there is not enough cl to make it neutral."

Criterion 0

No response or a nonsensical response.

The first question on the Post-investigation test contain six parts (a-f). Each part was scored either with a "#" or a "L" because the nature of the question required a right or wrong answer before an explanation was attempted (see Appendix 6C-2, 6C-3). The one exception to this grading rule was the "d" part in which case a student could circle "possible" or "impossible", and receive a 3 score if their explanation pointed out that it was impossible because the compound is the same on both sides (hence not chemical reaction) or that it was possible because even though the formula was turned around (which made it look different) it was still the same compound.

example: "Nothing in the products was not in the reactants so the mere rewriting in the chemical shorthand changes nothing about the compound."

Criterion 3 responses for the six parts (using the preferred response to part "D") are summarized below. It should be noted that an incorrect initial response and/or an incorrect explanation would be sufficient to require a "1" score on each part.

Criterion 3 responses to Question 1

part a
Impossible. XZ and YQ (the reactant molecules) are not compounds because they each contain ions with like charges.

part b
Impossible. XZ would not form a compound because it is composed of ions of like charge.

part c
Possible. No explanation is required by the question.

part d
Impossible. ZY and YZ are the same compound, so no chemical reaction has occurred.

part e
Possible. No explanation is required by the question.

part f
Possible. No explanation is required by the question.

The grading criteria for question 2 of the post-learning cycle test will be listed separately followed by example responses to the question.

Criterion 3

Recognition that weight is not conserved but the explanation discusses an excess of either reactant A or reactant H.

Example Response

"You might have lost some weight somewhere in the reaction or one of the compounds did not react completely."

Criterion 2

Impossible reaction because weight is not conserved; or a third product that is gaseous is suggested to account for the weight difference.

Example Response

Some kind of gas escaped from the beaker when it was heated or when the chemical reaction took place.

Example Response

"Some substance(s) must have been lost--conservation of mass. Also, redistribution of weight is due to double displacement.

Criterion 1

No recognition of a weight discrepancy; or an unreasonable accounting for the weight loss.

Example Response

"When A was mixed with H and heated, it gained weight by one gram and it turned into R. When H was mixed with A, it lost weight by two grams and turned into D.

Example Response

"In a chemical reaction the products lose weight so the reactants are heavier than the products."

Example Response

"1 gram of weight was lost during heating and the new compounds had different weights."

Criterion 0

No response or an answer that does not regard the question at all.

Appendix 6D

BAR Written Comments

BAR Written Comments

LC- 7 CLASS 125 N = 26 , 13 with comments

Lesson Control, T_2 (Demo)

	+	0	-	Comments
Lab				No Labs - 2
Discussion	2		1	
Demo				
Questions				
Problems	4			
Readings				
	6	0	1	

	#	Comments
I'm Confused	6	
Activities Not Logical		
Too fast		
Too slow		
I Understand	3	
I Like	3	
I Don't Like	1	
Activities Are Logical	1	
	14	

Quotes: "I like best about the activities we've done in class are the balancing of elements because it is mainly mathematical and a bit challenging. I really don't dislike the activity except it is getting a little tedious sitting everyday, seemingly doing the same stuff. I think we ought to break away every now and then."

"I found this unit pretty difficult but very interesting. The work was quite difficult, but with a little help I was able to do the work. I would like to do some labs instead of writing what we think."

6D-2

BAR Written Comments

LC- 7　　CLASS 122　　N = 19, 6 with comments

Lesson Control - Control

	+	0	-	Comments
Lab	1			
Discussion	2			
Demo				
Questions				
Problems				
Readings				
Lecture				
	3			

	#	Comments
I'm Confused	1	
Activities Not Logical		
Too fast	1	
Too slow		
I Understand		
I Like	4	
I Don't Like		
Activities Are Logical		
	6	

Quotes:

6D-3

BAR Written Comments

LC- 7 CLASS 121 N = 20 , 7 with comments

Lesson Control - Control
not in experiment

	+	0	-	Comments
Lab	2			
Discussion	2			
Demo				
Questions				
Problems				
Readings				
Lecture			1	
	4	0	1	

	#	Comments
I'm Confused	1	
Activities Not Logical		
Too fast		
Too slow	1	
I Understand		
I Like	1	
I Don't Like		
Activities Are Logical		
	3	

Quotes:

6D-4

BAR Written Comments

LC- 7 CLASS 116 N = 24 , 24 with comments

Lesson Control - R

	+	0	-	Comments
Lab				Need to do Lab - 4
Discussion			4	
Demo				
Questions				
Problems	5			
Readings	1		6	
Lecture			1	
	6	0	11	

	#	Comments
I'm Confused	7	
Activities Not Logical		
Too fast	2	
Too slow	1	
I Understand	2	
I Like	3	
I Don't Like	7	
Activities Are Logical		
	22	

Quotes: "This unit is too slow moving and too heavy. I find myself feeling like I am wading through jello."

"I like this topic because it's fairly simple to comprehend and a test over it wouldn't be too hard. I dislike this unit because I feel it would be easier for me if I had done the lab myself, but still the lab reading was plentiful in information."

"I liked nothing least or best. The entire unit is just kind of there. It is mildly amusing, but stimulates me to no emotion beyond that."

6D-5

"The thing I like the least about this unit is the discussions are kind of broad and there isn't enough class interaction. I also think a lab, like the one presented in the Idea-Reading, that produced Lead Iodide, would be helpful in demonstrating chemical reactions and it would make it easier to understand what takes place in a chemical reaction."

"There isn't anything in particular that I liked best about this unit. I did, however, find this unit to be fairly monotonous, uninteresting, and unclear."

BAR Written Comments

LC- 7 CLASS 114 N = 14 , 13 with comments

Lesson Control - Control
not in experiment

	+	0	-	Comments
Lab	8			
Discussion	2		1	
Demo				
Questions	1		1	
Problems	1		1	
Readings			3	Answering Reading questions mentioned
Lecture				
	12	0	6	

	#	Comments
I'm Confused	2	
Activities Not Logical		
Too fast		
Too slow	1	
I Understand	2	
I Like	2	
I Don't Like	2	
Activities Are Logical		
	9	

Quotes:

BAR Written Comments

LC- 7 CLASS 111 N = 22 , 21 with comments

Lesson Control - T_1

	+	0	-	Comments
Lab				Wants to do more labs - 8
Discussion	3			
Demo				
Questions				
Problems	4		1	
Readings				
Lecture	1		9	
	8	0	10	

	#	Comments
I'm Confused	5	
Activities Not Logical		
Too fast	1	
Too slow		
I Understand	1	
I Like	6	Mostly "I liked the topic"
I Don't Like	3	
Activities Are Logical	2	
	18	

Quotes: "I like doing the labs when we get to do something and see a reaction take place, but when we learn about something where the teacher just talks about whatever we are supposed to learn I get lost."

"I enjoyed learning something new but I didn't like the way we went about it. In my opinion I think I learn more taking notes than I do when we are in lab even though I don't like taking notes."

"Like - the way it is being taught and in the order it is being taught. I wish we could prove more things by ourselves than just having to take for granted that it is true. Dislike - I wish we could go slower to make sure I've got everything down right. As I said before I wish we could prove more things by ourselves other than taking for granted that it is true."

"I do not like taking notes as much as we do, but if that is what it takes to learn the things we need to know before we can do other labs etc., that is what we will have to do."

"I think it might be more interesting if we didn't go so long without a lab. Maybe we could stop our study for one or two days and do a lab that will teach us something on another subject. Then we could come back and work on this subject refreshed and happy."

"I like the discussion because I understood a little more when we talked about it. I hated just sitting here taking notes! I lost interest very quickly! (Also didn't understand)"

"I like working out all the chemical reaction problems. They are pretty fun. Taking notes is pretty boring, though."

Appendix 7A

Student Materials for LC-8

INVESTIGATION 8

Name____________________

Section_________________

GATHERING DATA
COMBINATIONS WITH ZINC

A. Label a clean 18 x 150 mm test tube as system #1 and dispense approximately 10 ml of copper (II) sulfate solution into it.

B. Add one piece of mossy zinc metal to the $CuSO_4$ solution and observe the system carefully for 3 to 5 minutes. Record your observations.

C. Is there any evidence for a chemical change in system #1? If so, specify.

D. Slowly add 15 drops of concentrated sulfuric acid (H_2SO_4) to system #1, shake gently to mix, and record your careful observations.

E. Is there any evidence for a chemical change as a result of adding the acid to system #1? If so, specify.

F. Set system #1 in your test tube rack and label a second clean, 18 x 150 mm test tube as system #2. Dispense approximately 10 ml of copper (II) chloride solution into the system #2 test tube.

G. Add one piece of mossy zinc metal to the $CuCl_2$ solution and observe the system for 3 to 5 minutes. Record your observations.

H. Is there any evidence for a chemical change in system #2? If so, specify.

I. Slowly add 15 drops of concentrated hydrochloric acid (HCl) to system #2, shake gently to mix, and record your careful observations.

J. Is there any evidence for a chemical change as a result of adding the acid to system #2? If so, specify.

K. Set system #2 in your test tube rack. After the systems have been allowed to sit for about 10 minutes, record final observations on both systems.

System #1	System #2

THE IDEA
QUESTIONS

Name_______________________
Section____________________

1. If you restrict yourself to the list of common ions, what products could possibly have been formed by the chemical changes you observed in system #1?

2. If you restrict yourself to the list of common ions, what products could possibly have been formed by the chemical changes you observed in system #2?

EXPANDING THE IDEA

Name______________________
Section____________________

A CHEMICAL POWER SOURCE - DEMONSTRATION
NOTES

A. Describe the function of an ammeter and a voltmeter.

B. Sketch the chemical cell apparatus and label the parts.

C. How does the operation of the apparatus illustrate the transfer of electrons in the reactions studied in this investigation?

EXPANDING THE IDEA
READING 8

THE SAGA OF BATTERIES -- A SHOCKING STORAGE

Oxidation - reduction reactions appear in a wide variety of situations. Reaction of calcium metal with water, magnesium metal with air, and iron metal with water and air (rusting) are examples of oxidation - reduction reactions. Other examples include digestion of food, burning of organic substances (such as wood, coal, and fuel oils), and the reactions involved in the processes of photosynthesis. The list of examples that could be written is almost endless, but one set of oxidation - reduction reactions that has great practical value to all of us is the set of reactions involved in electrical batteries.

You have seen one example of an electrochemical cell in the demonstration using copper and zinc. A battery is usually a collection of two or more electrochemical cells connected together in such a way to produce a desired voltage, so we could have made a battery from our demonstration apparatus by connecting several cells together. Most car batteries, for example, consist of six cells, each of which produces 2 volts for a total of twelve volts. Submarines utilize the same type of battery as a car (that is, a lead-acid battery), but 125 cells are required in each battery to produce 250 volts and each cell weighs approximately one ton. Sometimes even single cells are referred to as batteries, as in 1.5 volt flashlight "batteries."

Batteries are placed under one of two general classifications: primary or secondary. A primary battery is designed to be discharged once and discarded (flashlight batteries, for example), because it is more economical to buy a new one than it is to recharge the spent battery. Secondary batteries, on the other hand, are designed to be recharged several times during their useful lifetime. It is this second type of battery, specifically the lead-acid battery, that we will use to talk about the chemical changes involved in producing electrical current in batteries.

A lead-acid cell consists of two separate plates (or electrodes), which are submerged in a sulfuric acid electrolyte solution. On one of the plates the oxidation half of the oxidation - reduction occurs, and the reduction half of the oxidation-reduction reaction occurs on the other plate. It is necessary for the electrons involved in the oxidation - reduction reaction to move through an external conductor (wire) to get from one plate to the other, and it is this property that makes the reaction useful in producing electrical energy.

It is often convenient, when discussing oxidation-reduction reactions to study the oxidations and reductions separately by equations that are called half-reactions. For our lead-acid cell example the oxidation occurs at a plate made of lead, according to the following equation.

equation (1) $Pb + H_2SO_4 \longrightarrow PbSO_4 + 2H^+ + 2e^-$,

where e^- is the symbol for an electron. Notice that the lead on the plate starts out neutral and gives up two electrons to become Pb^{2+} in lead sulfate. Two spectator ions are involved in this oxidation half-reaction; the hydrogen ion and the sulfate ion. Sometimes, for the sake of simplicity, spectator ions are left out of half-reaction equations. If we were to omit the spectator ions from the half-reaction in equation (1), we would be left with

equation (2) $Pb \longrightarrow Pb^{2+} + 2e^-$.

The reduction half-reaction occurs at a plate made of PbO_2, according to the following equation.

equation (3) $PbO_2 + H_2SO_4 + 2e^- + 2H^+ \longrightarrow PbSO_4 + 2H_2O$.

Careful examination of equation (3) indicates that lead is the element being reduced. This is determined by assuming that oxygen has a 2- charge characteristic, when it is in a compound. This assumption means that lead in PbO_2 has a 4+ charge. The reduction skeleton equation then becomes

equation (4) $Pb^{4+} + 2e^- \longrightarrow Pb^{2+}$.

We can obtain the overall oxidation and reduction by adding equations (2) and (4) together, as follows:

$$\begin{array}{ll} \text{equation (2)} & Pb \longrightarrow Pb^{2+} + 2e^- \\ \text{equation (4)} & \underline{Pb^{4+} + 2e^- \longrightarrow Pb^{2+}} \\ & Pb^{4+} + Pb + 2e^- \longrightarrow 2Pb^{2+} + 2e^- \end{array}$$

, which can be simplified by deleting electrons from both sides. The result is:

equation (5) $Pb^{4+} + Pb \longrightarrow 2Pb^{2+}$, and we see that lead is both oxidized and reduced in this cell. To obtain the oxidation-reduction reaction of the cell complete with spectator ions, we can add half-reaction equations (1) and (3) as follows:

$$\begin{array}{ll} \text{equation (1)} & Pb + H_2SO_4 \longrightarrow PbSO_4 + 2H^+ + 2e^- \\ \text{equation (3)} & \underline{PbO_2 + H_2SO_4 + 2e^- + 2H^+ \longrightarrow PbSO_4 + 2H_2O} \\ & PbO_2 + Pb + 2H_2SO_4 + 2e^- + 2H^+ \longrightarrow 2PbSO_4 + 2H^+ + 2e^- + 2H_2O \end{array}$$

Removing common terms from both sides, we get the overall result:

equation (6) $PbO_2 + Pb + 2H_2SO_4 \longrightarrow 2PbSO_4 + 2H_2O$.

Equation (6) shows us reactants (left side of the arrow) and products (right side of the arrow) that are involved in the discharge of the battery. The charging process involves the reversal of this chemical reaction such that the substances on the right side of equation (6) become the reactants to produce the substances on the left side of equation (6). Can you see how the charging process also involves an oxidation-reduction reaction?

As stated before, all batteries work by utilizing oxidation-reduction reactions. In fact, all batteries are composed of plates separated by some electrolyte, but they are not always lead plates and sulfuric acid electrolytes. For some applications, such as flashlight batteries, a liquid electrolyte would be impossible to use. For such situations, the electrolyte is suspended in starch or some other material that will allow for the electrical connection necessary between the plates, but that will not spill out when the battery is jostled around.

The next time someone asks you how a battery works, you can show them this reading and let it give them a charge.

READING 8
QUESTIONS

Name____________________
Section____________________

For purposes of these exercises, assume that hydrogen is always 1+ and oxygen is always 2-, when they are part of a compound.

1. Which elements are oxidized and which are reduced in the following reaction?

$$4HCl + MnO_2 \longrightarrow MnCl_2 + Cl_2 + 2H_2O$$

2. How many electrons are lost by the oxidations, in the reaction above, and how many electrons are gained in the reductions?

3. List the spectator ions (name and formula) in the following reaction.

$$Cu + 4HNO_3 \longrightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$$

4. Is it possible for a spectator ion in an oxidation-reduction reaction to be oxidized or reduced? Explain your response.

5. Is it possible for the amount of oxidation to exceed the amount of reduction in a given oxidation-reduction reaction? Logically support your response.

Appendix 7B
Teacher Materials for LC-8

Investigation 8
Discussion Notes

A. Begin the discussion with sections B and C of part II of the Teacher's Guide for Investigation 4. This will include the observational evidence for a chemical change and the predicting of products for the systems in this investigation.

B. Discuss the Zn + $CuSO_4$ reaction. Ask the students what Zn is made up of as a reactant. (30^+, 30^-) What is Zn made up of as a product? (30^+, 28^-) Continue a similar line of questions concerning the Cu. Discuss the role of the SO_4^{-2} ion and invent the term, spectator ion.

C. Define oxidation as the loss (or apparent loss) of electrons. Define reduction as the gain (or apparent gain) of electrons. Discuss that the amount of oxidation must equal the amount of reduction in an oxidation-reduction reaction.

D. The conceptual invention is that some chemical reactions involve changes in the electron structure of atoms.

B. Section B Discussion

1. Ask the students to reiterate any evidence they had for chemical change in section B.2. With consensus that there was a chemical change, ask them to name the substances that reacted together.

NOTE: If water is suggested as a possibility, place a piece of zinc in a large test tube and put in some distilled water. Leave this system out in view of the students throughout the discussion.

2. When copper (II) sulfate and zinc have been named, as the substances that reacted, write their formulas on the board and label them "reactants."

3. Ask the class what the result of this chemical reaction was; i.e., what was produced by the chemical reaction.

    a. This question may be difficult for the students to answer because the copper produced does not have a luster.

    b. At this time, you should produce a sample of spongy copper, press it (as described earlier) and pass it around for the class to observe.

    c. When the class has agreed that the substance is copper, write its formula on the board in the appropriate place.

    d. Ask the students to determine what other substance (or substances) might have been produced. Direct their attention to the formulas for the reactants.

    e. If someone suggests zinc sulfate, write its formula on the board in the appropriate place. The formula will, in all probability, have to be supplied by the teacher. Ask if the reaction is balanced as written. (Yes).

4. Label the substances on the right hand side of the arrow as "products."

5. Ask the students to describe their observations when they added the concentrated sulfuric acid to the system. List these observations on the board.

6. Ask if the sulfuric acid became involved in a chemical reaction. Work with the students in discussion to help them deduce, from the observations, that:

    a. the sulfuric acid reacted with the zinc and not the copper; and

    b. the products of the reaction between sulfuric acid and zinc were hydrogen gas and zinc sulfate (have the students dictate a balanced equation).

NOTE: The question of the disappearance of the color will be discussed along with the reaction of section C. Retain the board list of observations for that discussion.

C. Section C Discussion

1. Using methods similar to those used in the discussion of section B, obtain reactants, products, and a balanced equation for the reaction in section C.2.

2. Proceed with the discussion of the hydrochloric acid addition, as was done for the sulfuric acid addition in section B.

3. Ask if there are any additional observations that should be added to the list on the board or if there are any observations that do not apply to both systems. Note the suggestions on the board.

4. Focus the attention of the class on the disappearance of the color from both solutions as the reactions proceeded. Ask them to suggest reasons for this phenomenon. This should be done with as much student input as possible. (This color disappearance will, of course, correspond to the reaction of all the copper compound.)

5. If their observations indicate that the solutions were still colored when the acids were added, ask if it is possible that both reactions were occuring simultaneously in the two systems (yes). Have them defend their positions with observational evidence. (Further disappearance of color and gas production.)

Investigation 8
Invention lecture notes

A. Introduce the lecture by stating that "some chemical reactions involve changes in the electron structures of atoms."

B. An example of this type of reaction involves the combination of zinc metal with copper (II) sulfate.

1. First of all, the products of the reaction must be determined. The copper and zinc will not combine; so, if there is to be a chemical change, it will have to result in the formation of zinc sulfate and copper metal (using common ions).

2. When we write down this relationship, we see that it is already balanced:

$$\mathrm{Zn} + \mathrm{CuSO_4} \longrightarrow \mathrm{Cu} + \mathrm{ZnSO_4}.$$

(Point out how the total number of reactant atoms equals the total number of product atoms.)

3. Underneath the symbols for zinc and copper (on both sides of the equation) write the number of protons and electrons indicated by the formulas, as follows.

$$\begin{array}{lllll} \mathrm{Zn} & + \mathrm{CuSO_4} & \longrightarrow & \mathrm{Cu} & + \mathrm{ZnSO_4} \\ 30+ & 29+ & & 29+ & 30+ \\ 30- & 27- & & 29- & 28- \end{array}$$

4. Point out that, in moving from the reactant side to the product side that zinc loses two electrons and goes from neutral to 2+ in charge. At the same time, copper gains two electrons and goes from 2+ to neutral.

C. Define oxidation as the loss (or apparent loss) of electrons and show how the change in zinc fits this definition.

D. Define reduction as the gain (or apparent gain) of electrons and show how the change in copper fits this definition.

E. Point out that the sulfate ion stays the same throughout the reaction; that is, it is neither oxidized nor reduced. It is, therefore, referred to as a spectator ion.

F. As another example of an oxidation - reduction reaction, use

$$\mathrm{Zn} + 2\mathrm{HCl} \longrightarrow \mathrm{ZnCl_2} + \mathrm{H_2}$$

(Use the same basic procedure as before; writing reactants, predicting products, and balancing the equation.)

1. Point out that zinc is oxidized (go through the process), that hydrogen is reduced (go through the process), and that chloride is the spectator ion.
2. End by stating (and showing with the equation) that the amount of oxidation must equal the amount of reduction in an oxidation-reduction reaction.

Investigation 8
Expansion Discussion

In the expansion discussion do not use the terms oxidation and reduction. Discuss the activity in terms of gaining or losing electrons and forming ions.

Appendix 7C
CAT Tests for LC-8
and Grading Criteria

Name____________________
Section__________________
Date____________________

1. Consider the equations for two chemical reactions:

(1) $SnCl_2 + Hg_2(NO_3)_2 \longrightarrow Sn(NO_3)_2 + Hg_2Cl_2$

(2) $SnCl_2 + 2Hg(NO_3)_2 \longrightarrow Sn(NO_3)_4 + Hg_2Cl_2$.

(a) In what ways are these two reactions similar?

(b) In what ways are these two reactions different?

2. Consider the equations for two chemical reactions:

(1) $SnCl_2 + 2HgCl_2 \longrightarrow SnCl_4 + Hg_2Cl_2$

(2) $SnCl_2 + HgCl_2 \longrightarrow SnCl_4 + Hg$.

(a) In what ways are these two reactions similar?

(b) In what ways are these two reactions different?

3. Consider the reaction:

$$4HCl + MnO_2 \longrightarrow MnCl_2 + Cl_2 + 2H_2O.$$

(a) Discuss the Cl atom in this reaction as a reactant and as a product.

(b) Explain the transformation from reactant to product.

Rationale, Construction and Grading Criteria for CATs for LCB

The content achievement tests (CATs) were given to measure the level of the student's understanding of the concept. The central concept of Learning Cycle 8 was that some chemical reactions involve changes in the electron structure of atoms. The one form of the CAT in LC-8 consisted of three questions. The first two questions gave the students an opportunity to look for similarities and differences between two chemical reactions. The third question presented an oxidation-reduction reaction and asked the student to discuss one kind of atom as a reactant and as a product. Each question contained two parts which was scored as one. The general scoring criteria was discussed in Chapter Two of this report. The CAT for LC-8 was given either two or three times to each class depending on the experiment design for that particular class.

The specific grading criteria for each question of the CAT for LC-8 will be given followed by examples of student responses which illustrate each grading criterion for each question.

Grading Criteria for Question 1 of CAT LC-8

Question 1 - Criterion 3

(1) Equation two is an oxidation-reduction reaction in which tin (II) goes to tin (IV) and mercury (II) changes to Mercury (I).

(2) In equation two there is an exchange of electrons between tin and mercury. Equation 1 is an ion exchange reaction.

NOTE: The response to part (a) was ignored unless it contained a misconception.

Question 1 - Criterion 2

(1) An incomplete answer in which they label the reactions but do not explain their reasoning.

Question 1 - Criterion 1

(1) Their answer contains a misconception.

(2) A common response addressed the number of nitrate ions in each equation rather than the oxidation state of the positive ions.

Question 1 - Criterion 0

(1) Blank or no answer.

(2) Nonsense answer.

Examples of Criterion 3 Responses for Question 1

Response 1

Reaction 1 is a simple double-displacement reaction. Reaction 2 is an oxidation-reduction reaction. The tin (II) atom loses 2 electrons and becomes tin (IV). 2 electrons are gained by the 2 mercury (II) atoms, (1 each) mercury (II) to mercury (I).

Response 2

In equation 1 all of the elements in the products have the same charges of those in the reactants. In equation 2 the tin was oxidized to form tin (IV) and the mercury formed mercury (I).

Response 3

In #1, all of the elements in the products have the same charges of those in the reactants. In #2, the tin was oxidized to form tin (IV) and the mercury formed mercury (I).

Examples of Criterion 2 Responses for Question 1

Response 1

Both don't use oxidation and reduction. The top is double displacement, the bottom involves electron gain and loss.

Response 2

One uses mercury (I) and the other mercury (II). The bottom reaction has an oxidation-reduction and the top reaction doesn't.

Response 2

Tin (II) stayed tin (II) in the first reaction. Mercury (II) stayed mercury (II) in the reaction. In the second equation tin (II) changed to tin (IV) and mercury (I) changed to mercury (II).

Examples of Criterion 1 Responses for Question 1

Response 1

There are more $SN(NO_3)_2$ in equation 2.

Response 2

The top mercury nitrate molecule has a neutral charge the bottom one has a negative charge.

Response 3

Balanced differently.

Response 4

The coefficient 2 preceding the mercury in the second reaction causes there to be 2 more (NO_3) atoms than in the first.

Response 5

The Sn gets reduced by gaining electrons in the second equation. The Hg is oxidized the second time - it gets more positive.

Question 2 of the CAT for LC-8 resembled question one in that the student was shown two equations and asked to state the similarities and differences in the two equations.

Grading Criteria for Question 2 of CAT LC-8

Question 2 - Criterion 3

part (a):
Both equations are examples of oxidation-reduction reactions.
part (b):
The equations are different by the number of electrons gained by each mercury ion. In equation #1 each of the mercury (II) ions gain one electron to become a mercury I ion. In the second equation the mercury (II) ion gains two electrons to become a neutral mercury atom. In each equation tin was oxidized, mercury was reduced, and there are two electrons being transferred.

Question 2 - Criterion 2

The answer should indicate that both equations are oxidation-reduction actions and doesn't show any specific misconceptions.

Question 2 - Criterion 1

(1) If the student states a misconception.

(2) If the student implies it is the number of ions in the formula that makes the equations different rather than the oxidation state of the positive ions.

Question 2 - Criterion 0

(1) No answer.

(2) Nonsense answer.

Examples of Criterion 3 Responses for Question 2

Response 1

part (a):
Both reactions are oxidation-reduction reactions. Both reactions start with $SnCl_2$ as a reactant and end with $SnCl_4$ as a product. Tin (II) is the thing being oxidized. It loses two electrons and becomes tin (IV). Mercury (II) is the thing being reduced. It gains two electrons.
part (b):
The mercury (II) in the second reaction is made a neutral element while the mercury (II) in the first reaction is changed to mercury (I).

Response 2

part (a):
They all involve the same types of atoms in the reactants and products. They are both oxidation-reduction reactions. The tin (II) in both reactions loses two electrons to become tin (IV).
part (b):
The two mercury (II) atoms gain one electron each to become mercury (I) in the first reaction. The mercury (II) gains two electrons to become neutral mercury in the second reaction.

Response 3

part (a):
Both reactions have $SnCl_2$ and $HgCl_2$ as reactants and $SnCl_4$ as a product. Both reactions involve the oxidation of tin -- tin (II) to tin (IV) -- and the reduction of mercury. Both equations involve oxidation-reduction.
part (b):
In reaction 1, mercury is reduced from mercury (II) to mercury (I), while in equation 2, mercury is reduced from mercury (II) to neutral mercury. Another difference is that reaction 1 uses twice as much $HgCl_2$ as does reaction 2. Lastly reaction 1 has Hg_2Cl_2 as a product while reaction 2 has neutral mercury as a product.

Examples of Criterion 2 Responses for Question 2

Response 1

part (a):
Both equations involve electron loss and gain -- oxidation and reduction.
part (b):
The way the electrons group together is different.

Response 2

part (a):
They both contain Cl^- as a spectator ion and tin (II) is changed to tin (IV).
part (b):
In equation 1 mercury (II) is changed to mercury (I) and in equation 2 mercury is changed to its elemental state.

Response 3

part (a):
The SN is being oxidized. The Hg is being reduced, and both equations are oxidation-reduction reactions.
part (b):
Different products.

Examples of Criterion 1 Responses for Question 2

Response 1

part (a):
The $SnCl_2$ in the reactants lost electrons to make $SnCl_4$.
part (b):
There are two more Cl in the product of equation 1.

Response 2

part (a):
Both reactions use tin (II) chloride and mercury chloride. Both are single ion displacement reactions.
part (b):
The first reaction uses two mercury chloride molecules while the second reaction uses only one. Mercury was produced in the second reaction but mercury chloride was produced in the first.

Response 3

part (a):
Single displacement, 2 atoms of Cl, joined with Hg before the reaction, ended up joining with the tin.
part (b):
In system 1 we have tin chloride and mercury chloride. In system 2 there is only tin chloride and mercury. The 2 $HgCl_2$ causes the Cl_2 to be in abundance.

Response 4

part (a):
Cl is the spectator ion in each of the reactions.
part (b):
Reaction 1 loses two electrons and reaction 2 gains two electrons.

Response 5

part (a):
2 Cl_2 combined forming Cl_4 in both equations. Chloride was a spectator in both equations. Both tin (II) went through reduction forming tin (IV).
part (b):
Equation 1 is a double displacement and equation 2 is a single displacement. Mercury went through oxidation in equation 2, losing two electrons to become neutral.

Question three of the CAT for LC-8 measured the level of the student's understanding of the concept using a different approach. The student was presented with an equation for an oxidation-reduction reaction and asked to discuss one kind of atom as a reactant then as a product. Parts (a) and (b) were scored as one question.

Grading Criteria for Question 3 CAT LC-8

Question 3 - Criterion 3

As a reactant the chlorine atom was an ion with a -1 charge. As a product the chlorine atom was found in two forms: (1) an ion with a -1 charge and (2) a neutral atom. Each of the two chlorine atoms with a negative one charge had lost one electron to become neutral chlorine atoms. An oxidation-reduction reaction had occurred.

Question 3 - Criterion 2

(1) An incomplete answer that recognized the equation was an oxidation-reduction reaction.

(2) An incomplete answer but the student discusses the chlorine atom with a negative one charge undergoing oxidation.

(3) An incomplete answer in which the student discusses the transfer of electrons.

(4) An answer in which the student identifies the Cl atoms with different charges but does not explain the transformation.

Question 3 - Criterion 1

(1) The student's answer contains a misconception.

(2) The student does not recognize that the equation is an oxidation reduction reaction.

Question 3 - Criterion 0

(1) Blank

(2) Nonsense answer

Examples of Criterion 3 Responses for Question 3

Response 1

part (a):
As a reactant, the Cl is an ion with a 1- charge. As a product some of the Cl is still a 1- ion. However, some of the Cl loses one electron per ion to form a netural atom.
part (b):
As a reactant 4Cl are combined with 4H. When MnO_2 was added, the Mn was reduced taking two electrons from the system. These electrons came from the 4Cl leaving two of the Cl atoms neutral and two of them still 1- ions. The ions combined with the now 2+ Mn ion.

Response 2

part (a):
The Cl atom starts out as a -1 ion because of one extra electron. Along the way two of the Cl ions lose an electron and become the neutral element chlorine. The other two Cl ions remain ions (-1) and they combine with Mn to form $MnCl_2$.
part (b):
The elements start off as ions in a compound. Then when two compounds are mixed the ions in the compounds switch places to form new compounds. Also part of the Cl ions lose an electron so they become the neutral element chlorine. The Mn ions gain the electrons lost by the Cl ions so they become +2 ions instead of the +4 ions.

Response 3

part (a):
The Cl as a reactant has a negative 1 charge, after the reaction the Cl loses an electron to form a neutral atom.
part (b):
The Cl loses two electrons (one electron each from two ions). These two electrons are picked up by the Mn to make it a Mn^{+2} instead of a Mn^{+4}. Cl formed two neutral atoms and two (-1) ions.

Examples of Criterion 2 Responses for Question 3

Response 1

part (a):
The chlorine changed from a negative ion to a neutral atom (molecule).
part (b):
The extra electrons from the chlorine were attracted by the manganese.

Response 2

part (a):
There were four Hs and four Cls in the reactant part. Then the Cl was broken down and the Mn took on two Cls and two were left alone. The charges on the two are different.
part (b)
No response.

Response 3

part (a):
Half of the Cl combined with manganese while the other half became a 'neutral' chlorine gas.
part (b):
Before it reacted, it had a -1 charge but as a product 1/2 still had a -1 charge but 1/2 had become neutral.

Response 4

part (a):
As a reactant, Cl is a 1- ion. As a product, some Cl is Cl^- while some is Cl_2.

part (b):
Cl starts out as Cl^-. Two Cl atoms remain Cl^- and combine with Mn^{2+}. The remaining $2Cl^-$ oxidize and become the neutral element, chlorine (Cl_2).

Examples of Criterion 1 Responses for Question 3

Response 1

part (a):
The Cl would be known as a spectator atom through out this reaction.
part (b):
While the reaction was occurring the Cl neither lost nor gained electrons when the new compounds were produced therefore it lost nor gained electrons during the reaction.

Response 2

part (a):
Before the reaction the coefficient 4 shows that the Cl atom will have 4 parts. The Cl is accounted for in $MnCl_2$ and when it is by itself Cl_2.
part (b):
Manganese joined with two chlorine atoms. The hydrogen joined the oxygen from the manganese oxide to form water. Chlorine was in abundance so it stands by itself.

Response 3

part (a):
Cl atom has an atomic weight of 17. In the reaction the Cl gas goes from concentrated to a less concentrated form. It intermixes with the Mn and still has some to spare.
part (b):
HCl and MnO_2 are mixed, when they are mixed, hydrogen gas is produced along with $MnCl_2$.

Response 4

part (a):
As a reactant the Cl is compounded with hydrogen. As a product there is a reduction reaction. The Cl is compounded with Mn but also neutral by itself.
part (b):
For Cl from the transformation from reactant to product there is a reduction reaction occurring. The Cl reduces.

Response 5

part (a):
As a reactant it was together as one molecule. As a product it was split into two and distributed evenly.
part (b):
In the reactant it was a compound. In the product it was by itself or one element.

Appendix 7D

BAR Written Comments

BAR Written Comments

LC- 8 CLASS 111 N = 21 , 20 with comments

Necessity - Control

	+	0	-	Comments
Lab	15		1	Many students complained about taking CATs
Discussion	1			
Demo			3	
Questions			3	
Problems				
Readings			4	
Lecture			2	Is lecture & Discussion confused?
	16	0	13	

	#	Comments
I'm Confused	5	
Activities Not Logical		
Too fast	1	
Too slow		
I Understand		
I Like	2	
I Don't Like	1	
Activities Are Logical		
	9	

Quotes: "I like the labs and being able to work with other students to figure out answers to questions. I feel like I learn more this way."

"I liked the lab the best, because I think I can learn by doing a lot better than by hearing someone talk all hour."

"The thing I like best about this Investigation is the lab that we did. I seem to be able to understand things more if I see how they work."

BAR Written Comments

LC- 8 CLASS 114 N = 18 , 18 with comments

Necessity - IE

	+	0	-	Comments
Lab				Need Lab - 1
Discussion	2			
Demo	11		2	
Questions	1		4	
Problems	1		3	
Readings	1		6	
Lecture			1	
	16	0	16	

	#	Comments
I'm Confused	8	
Activities Not Logical		
Too fast	1	
Too slow		
I Understand	3	
I Like	3	
I Don't Like		
Activities Are Logical		
	15	

Quotes: "I liked the chemical cell most but I didn't understand it until it had been re-explained a few times."

"I think the best thing was the demonstration. When I actually saw what was going on it was easier to understand."

7D-3

BAR Written Comments

LC- 8 CLASS 116 N = 23 , 23 with comments

Necessity GI_2 (I is lecture)

	+	0	-	Comments
Lab	16	1		
Discussion	4		1	Students confusing Lecture & Discussion?
Demo				
Questions			4	Several noted lack of follow-up in lecture
Problems	1			
Readings			1	No readings
Lecture			2	
	21	1	8	

	#	Comments
I'm Confused	3	
Activities Not Logical		
Too fast	2	
Too slow	1	
I Understand	1	
I Like	3	
I Don't Like	2	
Activities Are Logical		
	12	

Quotes: "What I like best, so far, of what we've done is the lab. I like least the lab questions because they're not explained."

"The lab was interesting, and the class discussion was good, but I don't feel we talked about everything in the lab. For example, we did not go over the questions we answered on the lab."

"Well, let's see. I guess it was all right. An "A" is certainly in order here. It was compact and, as far as I could see, complete. The only questions was, what was the topic? Was it the charge of electrons in a single-displacement atom, the oxidization/reduction principle, the spectator ion, or a more physical version? Sure, I understand the exchange of electrons, but what was the main idea? The investigation/ideas were clear, but the main purpose was slightly fuzzy."

6

BAR Written Comments

LC- 8 CLASS 122 N = 20 , 18 with comments

Necessity - GI, with I as discussion

	+	0	-	Comments
Lab	11			
Discussion	6		2	
Demo				
Questions			2	
Problems			2	
Readings				
Lecture				
	17	0	6	

	#	Comments
I'm Confused	2	
Activities Not Logical		
Too fast	1	
Too slow		
I Understand	1	
I Like	6	
I Don't Like	2	
Activities Are Logical		
	12	

Quotes:

7D-6

BAR Written Comments

LC- 8 CLASS 125 N = 19 , 13 with comments

Necessity - GE

	+	0	-	Comments
Lab	6			
Discussion				
Demo				
Questions				
Problems	1			
Readings			1	
Lecture				
	7		1	

	#	Comments
I'm Confused	3	
Activities Not Logical		
Too fast	2	
Too slow		
I Understand		
I Like	3	
I Don't Like	2	
Activities Are Logical		
	10	

Quotes: "I can't seem to answer the questions! They seem hard. I think we need to do more questions (maybe easier) until we understand it and get the full concept. Also we need to be reinforced on the basic concepts because sometimes they are overlooked and you think we understand! I still have a lot of questions that need to be answered."

"I was glad we were finally able to do a lab. Maybe I would have done better in understanding the atoms if there was some kind of lab we could have done with it to make it a little easier to understand."

7D-7

Appendix 8A
Student Materials for LC-10

INVESTIGATION 10

Name____________________

Section____________________

GATHERING DATA
HYDROGEN PEROXIDE AND MANGANESE DIOXIDE

A. Clean and dry your 125 ml erlenmeyer flask and determine its weight to two decimal places.

____

____

____

average ____________________

B. Add 1 spoonful of manganese dioxide (MnO_2) to the flask and weigh the system.

____

____

____

average ____________________

C. Compute the weight of MnO_2 in the system. Show your calculations.

D. Add 15 ml of hydrogen peroxide (H_2O_2) solution to the system. Test the gas being produced with a glowing wood splint. Record your observations.

E. When the gas production ceases, label the flask and put it in the place designated by your teacher.

F. When the flask is returned to you, weigh the system again.

____

____

____

average __________________________

G. Determine the weight of the contents of the flask. Show your calculations.

H. Record your observations of the contents of the flask.

8A-3

THE IDEA
QUESTIONS

Name____________________
Section____________________

1. How does the weight of the contents of the flask compare with the weight of manganese dioxide that you put in the flask? (i.e., what is the percentage weight change?

2. From the information obtained in sections A through H, what can you conclude about the identity of the contents of the flask? Explain.

8A-4

EXPANDING THE IDEA
H_2O_2 and MnO_2 REVISITED

Name____________________
Section____________________

A. Set up the laboratory apparatus according to your teacher's instructions. Be sure that the rubber tubing is inserted in the eudiometer.

B. Weigh out the designated amount of MnO_2 on a piece of waxed paper. Record the weight. ____________g.

C. Transfer the MnO_2 to the reaction test tube. When you are ready to begin taking data, add 5 ml of H_2O_2 solution to the test tube, stopper it immediately, and record gas volumes every minute for 5 minutes. Record your data in the following table.

MnO_2(g)	1 min. (ml)	2 min. (ml)	3 min. (ml)	4 min. (ml)	5 min. (ml)

D. At the end of the 5 minutes, dismantle your system and return the cleaned equipment to the place designated by your teacher.

E. Graph the volume data according to your teacher's instructions.

QUESTIONS

1. What general patterns do you see in the volume graphs?

2. Is there a relationship between the amount of catalyst and the rate of reaction? If so, state and explain the relationship. If not explain why there is no relationship.

FORM EXPERIMENT - DATA PRESENTATION
INVESTIGATION 10

GATHERING DATA - READING

A spoonful of manganese dioxide (MnO_2) was placed in an erlenmeyer flask. MnO_2 is a black powdery substance. The following weight data were obtained.

Weight Data (in grams)

Erlenmeyer flask	76.60
Flask and MnO_2	83.95
MnO_2	7.35

When hydrogen peroxide solution (H_2O_2) was added to the system, vigorous bubbling occurred and a blackish-gray mixture formed. A flammability test was performed on the gas being tested. The glowing wood splint burst into flames as it was lowered into the flask.

After the gas production stopped the flask was placed in an oven to dry the contents. The flask contained a crusty black solid. When the solid was broken up with a glass rod, it returned to a powdery substance. The following weight data was obtained.

Weight Data (in grams)

Contents and flask	83.94
Contents	7.34

THE IDEA
QUESTIONS

Name____________________

Section__________________

1. How does the weight of the contents of the flask compare with the weight of manganese dioxide that you put in the flask? (i.e., what is the percentage weight change?)

2. Using the information from the reading what can you conclude about the identity of the contents of the flask? Explain.

Expanding the Data
Reading 10a
H_2O_2 and MnO_2 revisited

You read earlier that MnO_2 catalyzed the evolution of O_2 gas when H_2O_2 decomposed according to the reaction:

$$H_2O_2 \longrightarrow H_2O + O_2$$

Figure one is a diagram of an apparatus which might be used to measure the amount of oxygen generated.

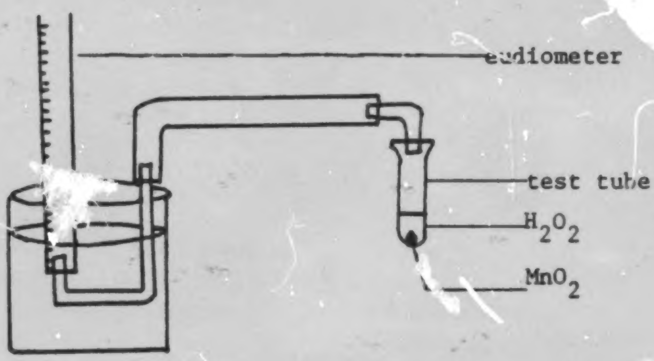


fig. 1

A eudiometer, which is a very long graduated test tube, is filled with water and inverted into a beaker of water. A glass tube is suspended below the mouth of the eudiometer and connected by rubber tubing to a reaction vessel which is a test tube. The test tube contains a measured amount of MnO_2.

5 ml of H_2O_2 is then added to the test tube and the evolved oxygen is collected in the eudiometer. The amount of oxygen evolved is measured every minute for five minutes. The whole experiment can be repeated with different amounts of MnO_2.

Table one contains the data collected for varying amounts of MnO_2.

Table 1

MnO_2(g)	1 min. (ml)	2 min. (ml)	3 min. (ml)	4 min. (ml)	5 min. (ml)
.1	1.4	2.6	3.5	4.3	5.1
.2	2.8	4.6	5.8	7.1	7.6
.3	4.9	7.2	8.8	10.2	11.3
.4	5.9	8.5	10.4	11.8	13.3
1.0	8.5	12.4	14.4	16.1	17.1
1.5	11.0	14.8	17.5	19.8	21.8
2.0	12.0	17.0	20.2	22.7	24.8
2.5	13.6	19.0	22.1	24.7	27.3
3.0	16.2	21.8	25.1	28.2	30.4

Figure two is a graph of data in table 1. It shows the relationship between volume of evolved oxygen vs. time for varying amounts of MnO_2.

Appendix 8B

Teacher Materials for LC-10

FORM EXPERIMENT - DATA PRESENTATION
INVESTIGATION 10

GATHERING DATA - DEMONSTRATION

(Teacher collects data with no student help.)

A. Follow the instructions in sections A through D from the student investigation. List the weight data and observations on the overhead transparency. Do not ask students for their observations.

B. Due to the time involved in the drying process, present the following data. This is data collected by students using the same procedure as above.

Weight Data (in grams)

	Group 1	Group 2	Group 3	Group 4
Erlenmeyer flask	76.60	75.34	75.44	74.36
Flask and MnO_2	83.95	82.58	81.72	80.73
MnO_2	7.35	7.24	6.28	6.37
Flask and contents	83.94	82.52	81.66	80.68

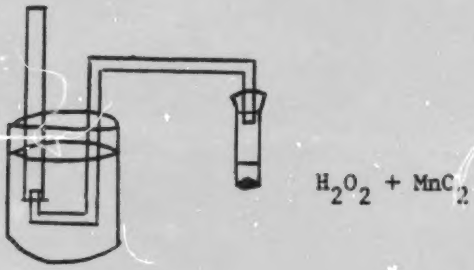
C. Describe the contents of the flasks and determine the weight of the contents of each flask.

6

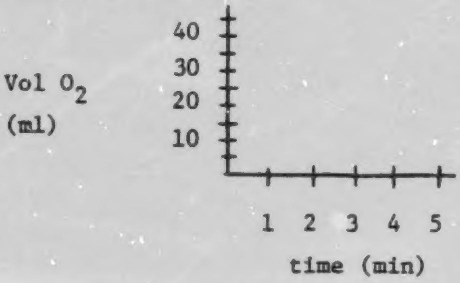
Expansion of LC 10 - Form of Data Presentation

Demonstration (based on "H_2O_2 and MnO_2 revisited")

Teacher sets up apparatus and describes (outlines) experimental procedure:



Using preweighed samples (.5, 1.0, 2.0g) of MnO_2 in the test tube. Add 5 ml of H_2O_2 and cork the tube. Using a stopwatch read level every minute for 5 minutes. Plot data on graph on overhead.



Discuss the results with the class.

Investigation 10
Invention Discussion Notes

A. Ask if a chemical reaction (or change) occurred in the H_2O_2 - MnO_2 system. (Chemical change occurred, as evidenced by the production of gas. Occasionally, though not often, heat production will be cited as evidence.)

B. Ask the students to identify the gas. (The gas is oxygen and most students have no trouble deciding this. There is, sometimes, a small popping noise, when the splint begins burning with a flame, and this noise causes some students to erroneously suggest that hydrogen is the gas being produced. Discussion of previous tests for hydrogen can help clear up the problems encountered here.)

1. Have the students specify the source of the oxygen (O_2) gas.

2. Write down proposed sets of reactants and products for as many equations as are proposed.

3. Balance, or attempt to balance, each of the relationships stated. Some relationships fall from discussion because they cannot be balanced; others can be balanced, but further analysis will show that they must be discarded. For example, students may suggest relationships that can be balanced, such as:

$$H_2O_2 + MnO_2 \longrightarrow H_2O + MnO + O_2$$

or

$$2H_2O_2 + MnO_2 \longrightarrow 2H_2O + Mn + 2O_2.$$

Either of these could be correct from the standpoint of oxygen gas production and a solid remaining in the flask, but neither of them will work when analyzed with respect to the weight data on the systems. It is at this time that the weight data, especially the percentage weight change, should be analyzed. When the students have agreed that the weight change is zero (for all practical purposes), have the students dictate the reactants and products. They may wish to continue putting MnO_2 on both sides of the equation. This procedure can be corrected in time.

C. Since MnO_2 appears on both sides of the equation and since all evidence points to the fact that the same amount of MnO_2 is present before and after the reaction, ask the students if H_2O_2 would have reacted without the MnO_2. (This discussion usually involves talking about students' experience with bottles of medicinal hydrogen peroxide solution. Usually, someone knows of a time that a bottle has been left open and has gone "flat".)

1. When there is consensus that the reaction described by the equation will occur without the manganese dioxide, ask what effect the addition of MnO_2 has on the reaction. (The MnO_2 speeds up the reaction.)

2. Point out (invent) that MnO_2 acts as a catalyst in this reaction. "Catalysts are substances that increase the rate of a chemical reaction, but are not used up in the overall reaction."

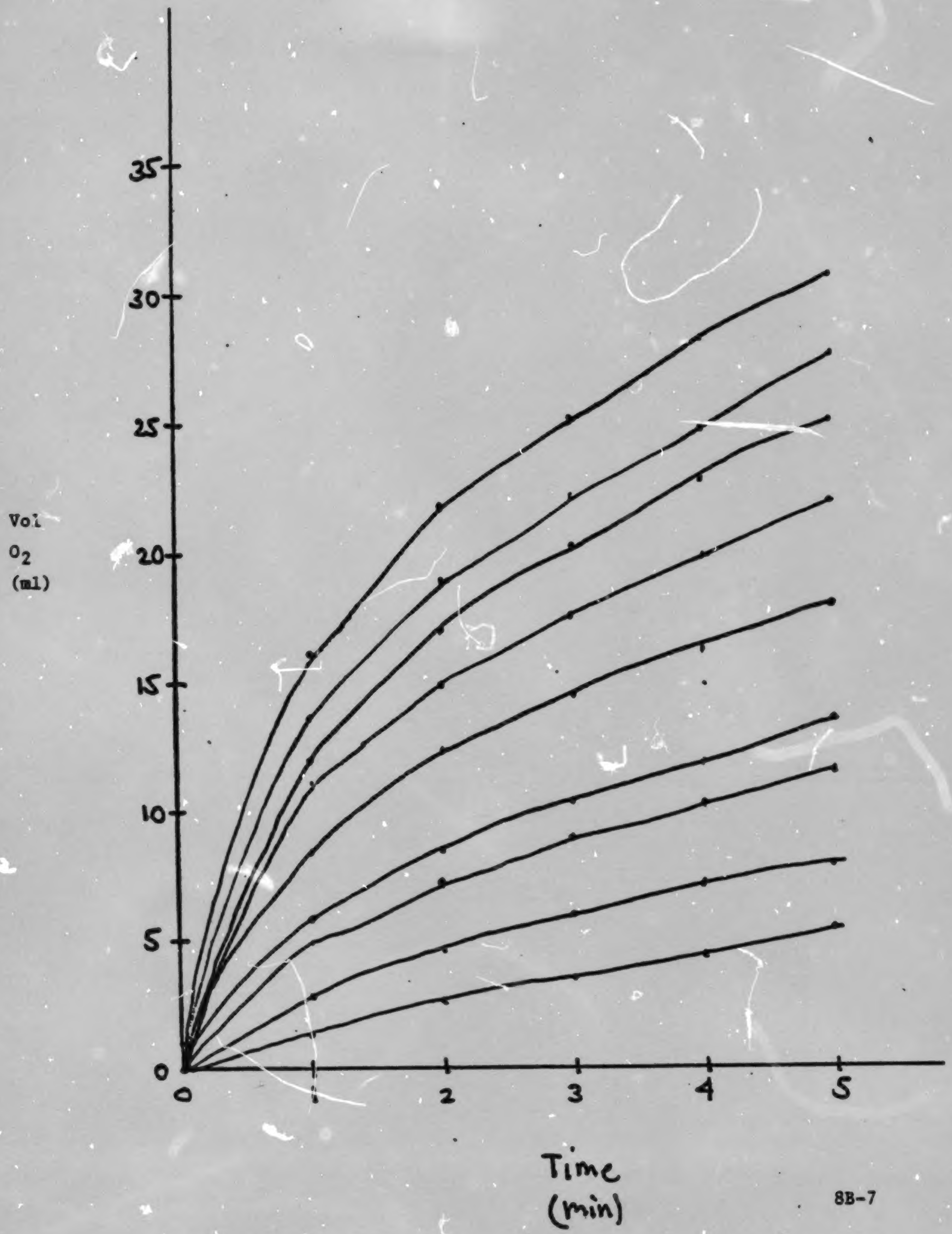
3. Tell the students that catalysts are not written with the reactants or products, because they undergo no net change, but their formulas are often placed over the arrow in the equation to show that they are present.

Expansion of LC-10 - Form of Data Presentation

Lecture

"G" Phase: Teacher diagrams apparatus on blackboard or overhead and outlines the experimental procedure (see Appendix 8A-6)

"F" Phase: Teacher presents data table (see Appendix 8A-9) and then graph (see Appendix 8B-6). With graph on the overhead, teacher discusses the data with the class.



8B-7

Appendix 8C

CAT Tests for LC-10

Name____________________
Section__________________
Date____________________
Code_____LC10-__________

Given the reaction

$$Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu.$$

In the spaces below, list three different ways that this reaction could be caused to speed up, and then explain how each of the listed methods would speed up the reaction.

1. (a) ____

   (b) explanation:

2. (a) ____

   (b) explanation:

3. (a) ____

   (b) explanation:

Name____________________
Section____________________
Date____________________
Code______LC10-______.

Information for four generalized chemical reactions is listed below. The times at the right tell how long it takes for each reaction to occur. Each different letter in an equation stands for a different element or compound, but a given letter will represent the same compound throughout the list of equations. The weights of the various substances in the reactions are written under the symbols for the substances.

	Reactants		Products	Time (seconds)
(a)	$\underset{4g}{A} + \underset{3g}{B}$	$\longrightarrow$	$\underset{4g}{D} + \underset{3g}{F}$	65
(b)	$\underset{5g}{A} + \underset{3g}{B}$	$\longrightarrow$	$\underset{4g}{D} + \underset{3g}{F} + \underset{1g}{A}$	58
(c)	$\underset{5g}{A} + \underset{3g}{B} + \underset{1g}{H}$	$\longrightarrow$	$\underset{4g}{D} + \underset{3g}{F} + \underset{1g}{A} + \underset{1g}{H}$	45
(d)	$\underset{5g}{A} + \underset{3g}{B} + \underset{2g}{H}$	$\longrightarrow$	$\underset{4g}{D} + \underset{3g}{F} + \underset{1g}{A} + \underset{2g}{H}$	30

1. Explain why reaction (c) is faster than reaction (b).

2. Explain why reaction (b) is faster than reaction (a).

3. Explain why reaction (d) is faster than reaction (c).

Description of CAT Tests, Rationale, Construction, Fit to LC Content and Grading Criteria for CATs in LC-10

Two different CAT tests were developed for this learning cycle. They are not equivalent forms. The purpose of the CAT that was administered prior to the learning cycle (see Appendix 8C-1) to serve as a diagnostic instrument regarding the students' foreknowledge of the concept of catalysis and the effect of concentration of reactants on rates of reaction. Succinctly stated, the central concepts of the learning cycle are: "Catalysts are substances that increase the rate of a chemical reaction but do not undergo a net change in the overall reaction"; and "the amount of catalyst used will directly affect the rate of reaction."

Three spaces were provided on the pretest for students to list ways that the rate of the reaction could be increased. Since there were two ideas of importance to this learning cycle the papers were scored only in terms of those two criteria.

Each of the three questions on the post test (see Appendix 8C-2) were scored separately. This second CAT test was administered at the end of the learning cycle and also six weeks after the learning cycle was completed. The questions dealt with the rate effects caused by the presence of a catalyst, higher concentrations of reactants and varying amount of catalyst.

The scoring of these CAT tests follows the general scale discussed in Chapter 2 of this report. The specific grading criteria and response examples for the pretest will be dealt with first.

Pretest

As mentioned earlier, only the catalyst effect and the reactant concentration effect were scored on the pretest. Answers given that dealt with additional factors (e.g., heating the system) were ignored in the scoring. The following is a list of the scoring criteria for the catalyst effect.

Catalyst Effect

Criterion 3: There must be a specific mention of the term "catalyst" and the explanation must indicate (a) that the catalyst is a substance and (b) that there is no net change in the substance.

Criterion 2: This involves recognition of a catalyst, by name, but no explanation is given, or one of the elements of the explanation from Criterion 3 is omitted.

Criterion 1: Failure to mention a catalyst, as one of three choices, or mention of catalyst with an incorrect explanation.

Criterion 0: No answer.

Concentration Effect

Criterion 3: Mention of concentration (or amount) effect. The explanation must relate the increased rate to the increased availability of reactant particles.

Criterion 2: Mention of concentration effect, but no explanation is given.

Criterion 1: No mention of a concentration effect, or a mention of concentration effect with an incorrect explanation.

Criterion 0: No answer.

Catalyst Effect Examples

Criterion 3: Use a catalyst. That speeds up the reaction, but remains the same -- spectator.

Criterion 3: Some kind of chemical which is a catalyst could be added. These are certain chemicals that can be added which will not react but whose purpose is to speed up the reaction taking place.

Criterion 2: Add a catalyst. This is adding another chemical to cause a faster reaction.

Criterion 2: Add a catalyst to the system. This will not react with the reactants, but will speed up the reaction.

Criterion 1: (There were no mentions made of catalyst where an incorrect explanation was given.)

Concentration Effect Examples

Criterion 3: Increase amount of reactants. With an increase in the amount there will be more particles to react thus making the reaction occur quicker.

Criterion 3: Use higher concentrations of the substances. The atoms would be greater in number and more likely to collide. This would speed the reaction up.

Criterion 2: Add more of $CuSO_4$ or Fn. To make the reaction happen faster.

Criterion 1: Add more Fn. Zinc is more reactive so it would lose more electrons and Cu would have to gain them.

Criterion 1: Put lesser amounts of each substance in. If you put lesser amounts of Zn and $CuSO_4$ in a test tube, the less time it would take them to react fully.

Post Test

A separate grading scale was necessary for each of the three questions in the post test. All three questions related to the same set of equations but each question related to a separate aspect of the topic of reaction rates. Question 1 asked the student to recognize that substance H was a catalyst; question 2 required that the student observe an increased rate due to an increase in reactant concentration; and question 3 asked the student to recognize the rate effect from an increase in amount of catalyst.

The following is a listing of the scoring criteria for each question. After the listing of a specific criterion, example student responses satisfying that criterion will be given.

Question 1

Criterion 3: Reaction (c) is faster than reaction (b) because H is a catalyst.

Example Response: Reaction (c) is faster than reaction (b) because a catalyst (H) was used.

Example Response: H is used as a catalyst in reaction (c). It speeds up the reaction but does not react.

Criterion 2: Recognition of catalysis but H is not specified as the catalyst.

Example Response: Because there was a catalyst in reaction (c) which sped up the reaction rate.

Criterion 1: Failure to recognize the presence of a catalyst or some specific misunderstanding relating to the equations or rates of reaction.

Example Response: Because A and H did not change and B just decomposed. A and H were catalysts.

Example Response: H is a catalyst and helped B and A react faster. Part of A acted as a catalyst.

(NOTE: The addition of the misconception of the second sentence in this response was the basis for assigning a "1" score to this response.)

Example Response: Because (c) has reactant H and (b) doesn't.

Example Response: Maybe because it has hydrogen in it and because it weighs more.

Criterion 0: No response.

Question 2

Criterion 3: Reaction (b) is faster than reaction (a) because of the increased concentration of A. The explanation must include some description of how the increased concentration would speed up the reaction.

Example Response: There was more of reactant A and the greater the amount of reactants the faster the reaction. The reactants will have more chance of hitting and reacting if there is more of them in the system.

Criterion 2: A recognition that there is more A present but the explanation given does not give a complete description of the effect more A has on the rate.

Example Response: The weights of A are different in reactions (a) and (b) by 1 gram. In the product of (b), A is present where in (a) it is absent. There is more weight, meaning more matter to work with in reaction (b) so the reaction time is less.

Example Response: The higher concentration of substance A in reaction (b) caused the reaction to occur quicker.

Criterion 1: Failure to recognize an effect due to concentration; or some other specific misconception relating to the question.

Example Response: There is more chance of the particles which are moving very quickly to rub against each other and lose electrons. There is more catalyst in (b).

Example Response: The amount of A increased. Part of A acted as a catalyst to help the reaction occur quicker.

Example Response: Because A did not change and B was just decomposed. A was a catalyst for B.

Criterion 0: No response.

Question 3

Criterion 3: Reaction (d) is faster than reaction (c) because a greater amount of catalyst H is present.

Example Response: Reaction (d) is faster because it has more substance H, which acts as a catalyst. We learned that the more catalyst there is the faster the reaction.

Criterion 2: Recognition of a rate change due to more but H is not specified as a catalyst.

Example Response: Because there is two grams of H in (d) and 1 gram in (c).

Example Response: Reaction (d) is faster because more of a catalyst is used. The more catalyst, the faster the reaction.

Criterion 1: Failure to recognize the significance of the amount of catalyst; misconceptions about which substances in the reaction are catalysts; or general statements indicating misconceptions relating to the question.

Example Response: Because 1 more gram of H was added or it was heated.

Example Response: Because (d) has more grams of reactant H than (c).

Example Response: It has H as a catalyst plus that little extra 1 gram of A.

Example Response: Reaction (d) is faster because it has one more gram of H than (c) does thus producing a new compound.

Example Response: Reaction (d) is faster than reaction (c) because A, which would be the catalyst, has more to combine with than reaction (c). H is larger in reaction (d) and speeds up the reaction.

Criterion 0: No response.

Appendix 8D

BAR Written Comments

BAR Written Comments

LC- 10 CLASS 111 N = 23, 23 with comments

Data Presentation - R

	+	0	-	Comments
Lab				No Lab Work - 4
Discussion	4		2	Like small group discussion Not class discussion
Demo				
Questions			1	
Problems	2		1	
Readings	4		6	
Lecture				
	10		10	

	#	Comments
I'm Confused	3	
Activities Not Logical		
Too fast		
Too slow		
I Understand	3	
I Like	6	I like topic
I Don't Like	1	
Activities Are Logical		
	13	

Quotes: "Since about the fifth grade I have heard the word catalyst, but I never really understood what it meant. Although most of my classmates would kill me for saying this, I really liked the 'novel'. There wasn't anything I disliked."

"We need to do some labs using catalysts (for fun), and I still would like to know why catalysts work the way they do."

"I hate doing the readings and no lab work."

8D-2

BAR Written Comments

LC- 10 CLASS 114 N = 15 , 15 with comments

Data Presentation - Control
with reading

	+	0	-	Comments
Lab	13		1	
Discussion	2		2	
Demo				
Questions	1		3	
Problems				
Readings	3		2	
Lecture				
	19		8	

	#	Comments
I'm Confused	1	
Activities Not Logical		
Too fast		
Too slow	1	
I Understand	1	
I Like	2	
I Don't Like		
Activities Are Logical	1	
	6	

Quotes: "I dislike the readings assigned to us. They are hard to understand."

"I liked all of this unit. We did a lot of labs, then thinking, then explanations, and readings. I am not confused (right now)."

"I liked essentially everything in this investigation. The questions seem to make sense. The discussions were easy to follow and I felt freer in lab to'experiment around' with my unanswered questions until discovered them on my own. I enjoyed learning about the catalyst. It seems useful and interesting.

8D-3

BAR Written Comments

LC- 10 CLASS 116 N = 27 , 26 with comments

Data Presentation -
Demonstration

	+	0	-	Comments
Lab				Need Labs - 3
Discussion	1		1	
Demo	13		1	
Questions	1		6	
Problems	4		2	Graphing
Readings				
Lecture				
	19		10	

	#	Comments
I'm Confused	3	
Activities Not Logical	1	
Too fast		
Too slow	2	
I Understand	1	
I Like	3	
I Don't Like	1	
Activities Are Logical	1	
	12	

Quotes: "I enjoyed the demonstrations very much. I might have enjoyed doing the lab ourselves."

"We get to see what really happens, instead of reading it out of a book."

"At the beginning of the investigation we were asked to give 3 ways in which to speed up a chemical reaction. We covered the use of a catalyst, and most people know about how heat helps, but we never covered the 3rd way in class."

"The think I liked the most was watching the lab procedure, instead of doing it."

8D-4

"I really like doing class demonstrations, or one experiment for the whole class. It makes it easier for me to understand."

I liked the demonstration because I didn't have to go do the lab myself. Also, I understood better why we were doing it."

"I dislike not doing the experiment. It would have been a little better if the student experienced doing the experiment."

"I liked the lab even though it was just a demonstration."

BAR Written Comments

LC- 10 CLASS 121 N = 23, 9 with comments

Data Presentation - Control
Not in experiment

	+	0	-	Comments
Lab	6			
Discussion	2		1	
Demo				
Questions			1	
Problems				
Readings			1	
Lecture				
	8		3	

	#	Comments
I'm Confused	1	
Activities Not Logical		
Too fast		
Too slow	2	
I Understand	1	
I Like	1	
I Don't Like		
Activities Are Logical		
	5	

Quotes:

8D-6

BAR Written Comments

LC- 10 CLASS 122 N = 20 , 20 with comments

Data Presentation - D/L

	+	0	-	Comments
Lab				Like Labs - 12
Discussion	2		2	
Demo				
Questions			1	
Problems			2	
Readings				
Lecture				
	2		5	

	#	Comments
I'm Confused	3	
Activities Not Logical		
Too fast	1	
Too slow		
I Understand	3	
I Like	7	
I Don't Like		
Activities Are Logical		
	14	

Quotes: "This activity was okay. I think it was taught in a pretty good way in that we were encouraged to make guesses and try to figure something out and try new ways before he told us if we were wrong or right. I do find it very hard though to listen to a teacher talk for the whole class period, especially if I'm not interested in the subject, and I learn better if we do things."

"So far I understand what we're doing pretty well. I could even answer that white sheet before this one! (I don't know if it's all right, but I think

I've caught onto the idea pretty well!) I think labs are a lot of fun so if we ever have a day that we're supposed to do a lab and we aren't in a hurry, can we go ahead and do it? Maybe not so often as before, but occasionally for a change of pace."

BAR Written Comments

LC- 10 CLASS 125 N = 16 , 4 with comments

Data Presentation - Control
No Reading

	+	0	-	Comments
Lab	3			
Discussion	1		1	
Demo				
Questions				
Problems				
Readings				
Lecture				
	4		1	

	#	Comments
I'm Confused		
Activities Not Logical		
Too fast		
Too slow		
I Understand		
I Like	1	
I Don't Like		
Activities Are Logical		
	1	

Quotes:

8D-9

Appendix 9A
Student Materials for LC-12

INVESTIGATION 12

Name____________________
Section_________________

GATHERING DATA
TEMPERATURE CHANGES AND DISSOLVING
PART I

A. Fill an 18 x 125 mm test tube half full with water and measure its temperature with a thermometer. Place two NaOH pellets in the water and agitate vigorously for about 15 seconds.* Test the temperature of the test tube and record your observations.

Repeat this procedure with fresh water using one spoonful of the following compounds. Record your observations.

B. NH_4NO_3

C. Anhydrous $MgSO_4$

D. Hydrated $MgSO_4$

PART II

A. Accurately weigh between 3 and 8 grams of $MgSO_4$ (anhydrous). Record the exact weight and show your work below.

---

*Do not touch the NaOH pellets or the solution with your hands. If you spill the solution wash immediately with running water and notify your teacher.

B. Suspend a thermometer in a polystyrene cup so that it is about ½ inch from the bottom. Using a graduated cylinder add 100 ml of water to the cup. Note the temperature of the water over several minutes until it is a constant value. Record the temperature.

C. Add the $MgSO_4$ to the water with vigorous mixing with a stirring rod. Occasionally, check the temperature of the solution. Record the highest temperature reached after all of the $MgSO_4$ dissolves.

D. Find the "change in temperature" (Δt) Show how you calculated this below.

E. Record your data on the table below. Obtain the data of the other students in your class and record the data on the table.

weight $MgSO_4$(g)	Δ t

F. Plot the weight of $MgSO_4$ vs. change of temperature on the graph on the next page.

THE IDEA
QUESTIONS

Name____________________
Section__________________

1. What conclusions can be drawn from the data in Part I?

2. What trend is shown by the data on the graph in Part II?

9A-6

EXPANDING THE IDEA
TEMPERATURE AND CHEMICAL CHANGES - DEMONSTRATION

Name________________________
Section______________________

NOTES

A. Describe what happens when solid $Ba(OH)_2(H_2O)_8$ is mixed with solid NH_4SCN.

B. Describe what happens when powdered Zn is mixed with $CuSO_4(H_2O)_5$ solution.

QUESTIONS

1. List evidence to indicate that the above interactions are chemical changes.

2. Write equations for the reactions.

3. Predict what the effect on the temperature would be if you varied the amounts of chemical reactants in this demonstration.

EXPANDING THE IDEA
READING 12a

MAKING THINGS HOT or cold

In investigation 12 you have been exploring chemical and physical systems which gain or release energy in the form of heat. The heat was noticed as a change in the temperature of the reacting media. When NaOH was dissolved in water, for example, the heat it lost was absorbed by the water into which it was dissolved and the temperature rose. The dissolving of NaOH in water is said to be exothermic because it releases heat. If you were to have used two times as much NaOH, the amount of heat released would have doubled and the temperature change of the water would have also doubled.

Heat is often confused with temperature. To distinguish the two consider the following experiment. If 5 grams of NaOH were put into a beaker containing 50 ml of water the temperature would be raised to 35°C. If a second beaker contained 100 ml of water, it would take 10 g of NaOH to raise the temperature to 35°C. Although the temperature is the same in both beakers, the container which has twice as much water has absorbed twice as much heat.

The amount of heat contained by an object is dependent on three factors. As shown in the example above, the weight of the object is one factor. Another factor is the temperature of the object. If you have two beakers which contain the same amount of water, the beaker which has the higher temperature contains the most heat.

The third and final factor which controls the amount of heat contained by an object is the material out of which the object is made. Different materials have a different ability to hold heat. This is called their heat capacity. Iron has less of a heat capacity than water. Using a constant heat source, it takes less time to heat 1 gram of Fe to 85°C than to heat 1 gram of water to the same temperature. The Fe has less heat to give up than water does.

Heat is expressed in units called calories. One calorie is the amount of heat necessary to raise one gram of water one degree centigrade. The amount of heat necessary to raise 10 grams of water from 25°C to 28°C is 30 calories (28°C - 25°C = 3°C; 3°C x 10 g water = 30 calories).

If you dissolve 5.6 g of KOH in 100 g of water the temperature of the water rises 14°C. The reason the temperature of the water rises is because the dissolving KOH gives off heat (i.e. the dissolving of KOH is an exothermic process). If all of the heat given off by the KOH is absorbed by the water (an approximation which is usually a pretty good one in a system like this), then the heat given off by KOH should be equal to the heat gained by the water. Since the amount of heat gained by the water is 1400 calories (100 g water x 14°C), the amount of heat lost by the KOH must have also been 1400 calories. The assumption is that 5.6 grams of KOH releases 1400 calories of heat.

This assumption is only good if all of the heat is transfered to the water. If some of it is transfered to the vessel containing the water or to the air above the vessel, then our value will have an error. If our vessel is made of a material which does not absorb heat and we do the reaction rapidly then our assumption will be very close to being accurate. The vessel which contains the water is called a calorimeter and although the polystyrene cups which you used during this investigation appear to be poor substitutes for "real" scientific equipment, they are actually one of the best calorimeters available.

Let us now return to the KOH dissolving. It was determined that 5.6 grams of KOH released 1400 calories of heat when it dissolved. If more KOH was used then more heat would be released. So the amount of heat would be 1400 calories per 5.6 grams of KOH or 1400 cal/5.6 g of KOH. The heat which is released is called the heat of solution for KOH. We can standardize this figure by dividing to find out how much heat is released per gram. This figure is 1400 cal/5.6 g = 250 cal/g. The heat released by one mole of KOH is called the molar heat of solution. Since 1 mole of KOH weighs 56 grams, the molar heat of solution for KOH is the amount of heat released when 56 g of KOH dissolves. The value is 250 cal/g x 56 g/mole = 14,000 cal or 14 kilocalories.

The amount of heat released or gained by a chemical reaction is called the heat of reaction. Since chemical equations express reactions in units of moles, the molar heat of reaction is a useful quantity. As an example consider the following reaction which was carried out in a calorimeter containing 1000 grams of water:

$$C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O.$$

Five grams of C_2H_5OH was burned in excess oxygen. The temperature of the water started at 25°C and rose to 60°C.

$$\begin{aligned}\text{heat released} &= \Delta t \times \text{weight of water}\\ &= 1000\text{ g} \times 35^\circ\text{C}\\ &= 35000 \text{ cal of heat released}\end{aligned}$$

since 5 g of C_2H_5OH has burned

the heat is: $\dfrac{35000 \text{ cal}}{5 \text{ g } C_2H_5OH}$

$$\text{or } \frac{35{,}000 \text{ cal}}{5\ \cancel{g}\ C_2H_5OH} \times \frac{46\ \cancel{g}}{1 \text{ mole}} = 322{,}000 \text{ cal/mole}$$

the molar heat is 322 kcal/mole

READING 12a
QUESTIONS

Name____________________

1. 100 grams of water are placed into a calorimeter at a temperature of 21.3°C. 4.34 grams of NH_4Cl are dissolved, during which the temperature of the water drops to 18.5°C. Compute the heat of solution for NH_4Cl in kcal/mole.

2. The molar heat of reaction for the following reaction is 673 kcal released per mole of $C_6H_{12}O_6$.

$$C_6H_{12}O_6(s)+6O_2 \longrightarrow 6CO_2(g)+6H_2O(l)$$

Calculate how much heat is released if 10 grams of $C_6H_{12}O_6$ is burned.

EXPANDING THE IDEA
INPUT HEAT - DEMONSTRATION/EXPERIMENT

Name______________________

Section____________________

A. Record your observations as your teacher lights a candle and heats $(NH_4)_2Cr_2O_7$.

B. Mix a half-spoonful each of ammonium chloride--NH_4Cl--and a calcium hydroxide --$Ca(OH)_2$--on a piece of paper. Transfer this mixture to an 18 x 150 mm test tube.

C. While holding the test tube with a wire test tube holder, warm the mixture gently with your burner and record your careful observations of the system.

QUESTIONS

1. Discuss if each of the reactions you observed are physical or chemical changes.

2. Discuss if each of the reactions you observed are endothermic or exothermic changes.

EXPANDING THE IDEA
READING 12b

GREMLINS AND OILY RAGS

In most laboratory situations people attempt to make their systems as simple as possible. The main reason for doing this is to limit the number of variables in the system so that they can better control their experiments. Data gathered from carefully controlled experiments can be used in developing mental conceptions (models) for the way systems work. The importance of models that are developed from experimental work is determined by how well those models can be applied to other chemical systems, whether they are simple or complex systems. The more we are able to generalize with our models and the more we can apply our models to complex systems, the more important our models are.

There are a wide variety of chemical systems, all of which involve the transfer of energy during the reaction (heat, light, and sound), and others absorb energy in the reaction process. Common to most of the systems is a simplicity that allows you to write specific formulas for reactants, predict specific products, and write balanced chemical equations for the interactions. In dealing with complex chemical systems we can look for observational evidence that will confirm (or deny) models that have been developed from the simpler systems. Observational evidence is quite important in working with the complex systems because it is difficult (often impossible) to write neat, clean, balanced equations for them.

Two such complex chemical interactions, which we will use in examining energy relationships in chemical change, are the frying of an egg and the burning of a piece of notebook paper. Notice that in both systems a chemical change will occur only after energy has been added to the systems. There are two important differences in these systems with respect to energy, however. First, it takes considerably less energy to start the egg frying reaction than is required to start the paper reaction. Second, when one stops adding energy to the egg, the reaction stops. By contrast, the paper reaction--once started--will continue after the initial energy source is removed. The reaction of the paper with air also gives off energy, primarily in the forms of heat and light.

Let's examine these two differences in more detail. One way to compare the amounts of energy necessary to start the reactions is to apply energy at the same rate to both systems. If, for example, we put the paper and an egg in the same pan and begin heating the pan, we observe that the egg soon begins changing chemically while the paper remains unchanged. Recall that the egg in Reading 2 changed chemically when the maximum temperature of the system was $100^{\circ}C$ (the boiling point of water). This latter statement gives a somewhat more quantitative evaluation of the minimum energy required to make the egg react. We won't pursue, at this time, a more exact determination of the minimum energy necessary for reaction. The important point to be understood here is that there is a minimum amount of energy required in a system before a chemical reaction will occur. This minimum total energy of the reactants is called the activation energy. It is clear from our examples that the activation energy of the paper-air reaction is much higher than that of the egg reaction.

Without the addition of energy neither of the example reactions would occur. The second difference between the two systems, however, occurs after the activation energies for the reactions have been achieved. It has already been noted that the paper reaction continues and the egg reaction stops, upon removing the activating energy source. It is necessary that activation energy be available for a reaction to continue, so the source of that energy must be determined (after the initial source has been removed). This will only apply to the paper system because it is the one that continues reacting. We observe that a lot of energy is given off by the paper system as a result of the chemical change. It is reasonable to assume that some of the energy given off by the reaction could go into raising nearby reactants to the activation energy point. This reaction would continue until the system was "cooled" or until the reactants could no longer come in contact.

Interestingly, the amount of energy given off by the reaction is greater than the activation energy. If this were not true, the reaction of substances we call "flammable"--wood, oil, gas, etc.--would be of no value for supplying heat energy that can be used for various purposes. Since it is true, we must conclude that the products of the reaction contain less total energy than the reactants contained. This difference in energy can be accounted for in the energy given off by the reacting system. Such a reaction, during which heat is given off, is called an exothermic reaction.

What about the reaction in the egg system, then? We can say for sure that there is not enough energy given off during that reaction to continue to activate other reactant particles. (Recall that the reaction stops when the activating energy source is removed.) The most reasonable explanation for this observation is that energy is absorbed during the process of changing reactants to products in this chemical change. In other words, the products have a greater total energy than the reactants. This type of reaction is termed an endothermic reaction. If the egg reaction were exothermic like the paper reaction, we would have a miserable time trying to cook (or eat) a fried egg!

Spontaneous combustion is a strange (and often destructive) phenomenon, which involves objects at low temperatures bursting into flame. When someone loosely piles oily rags in a poorly ventilated place, a good possibility exists for the occurrence of this phenomenon. This seems unreasonable, at first glance, because the activation energy for the reaction of oil and air or rag and air is much higher than that corresponding to room temperature. Let's examine the situation carefully and try to explain spontaneous combustion in terms of what we know about chemical changes.

The conditions under which spontaneous combustion occur are important. The rags are piled loosely, so there are many air spaces between the rags in the pile. This air is trapped in these spaces, which gives rise to the term "dead air spaces". There is no air draft through the spaces, and, since air is a poor conductor of heat, the lack of draft and the poor heat conduction property allow for heat generated in the air space to tend to remain there. It has been stated that room temperature does not provide the activation energy for the reaction. In general that is true, but review the idea of temperature again. Temperature measures the average kinetic energy of the particles in a system. Average values are typically composed of many values near the average, but a few values that are considerably higher and a few values that are considerably lower than the average. A few air and oil particles, therefore, will have enough energy to collide and achieve the activation energy for reaction. As you know, the reaction is exothermic, and if the heat does not escape, it will be absorbed by the system. The average kinetic energy of the region (air pocket) increases, logically resulting in a greater number of oil and air particles with enough energy to activate further reactions. If the heat from these reactions is produced faster than it is removed, we can easily see that it is just a matter of time before the reaction is occurring rapidly enough to produce a fire! The safety lesson to be learned from this discussion should be obvious.

One other aspect of activation energy can be explored, at this time. As you know, hydrogen peroxide decomposes so slowly at room temperature that it appears to be unreactive. When we added manganese dioxide, however, the reaction occurred quite rapidly with no net change in the manganese dioxide. Since the manganese dioxide was a catalyst and not a reactant, the chemical change that took place was the same as it would have been without the catalyst. The difference was that the reaction happened more rapidly at a lower energy level, when the catalyst was present. We have seen reactions speed up before, but this was usually due to heating, not the addition of a catalyst. The "speeding up" factor is common to both situations, however. The conclusion could be drawn, therefore, that a catalyst has the effect of lowering the activation energy required for a reaction to occur.

READING 12b
QUESTIONS

Name____________________
Section____________________

1. Why is spun fiberglass a better heat insulator than plate glass?

2. Compare the activation energies for the decomposition of hydrogen peroxide and the reaction of zinc with hydrochloric acid.

3. Why will the reaction between zinc and hydrochloric acid speed up, when the system is heated?

Appendix 9B

Invention Lecture and Discussion Notes for LC-12

Investigation 12
Invention Lecture

A. When substances are dissolved in water, they will either give off heat or absorb heat. In fact, reactions involve changes in the total energy of the reacting substances. The amount of energy is directly proportional to the amount of the reacting substances.

  1. Dissolving processes that give off heat are called exothermic processes. (Try to establish a perspective on whether heat is going in or going out; i.e., you take the position of reasoning with reference to the solute.)

  2. Dissolving processes that absorb heat are called endothermic processes. (Go through a similar reasoning pattern on this type of process.)

B. Point out that in an exothermic process, the energy comes from the substance and goes out into the environment; whereas, the opposite process occurs in an endothermic system.

  1. As examples, consider $MgSO_4$ in two solid forms: anhydrous (meaning that the solid has no water in it) and hydrated (meaning that the crystal has water bound up in it).

  2. Anhydrous magnesium sulfate will dissolve exothermically. If you put anhydrous $MgSO_4$ in water, the solution temperature will be higher than the original temperature of either the solid or the water. In the process of the dissolving, some of the stored heat will go from the $MgSO_4$ into the water. This results in the solution temperature increase.

  3. The hydrated $MgSO_4$ absorbs heat from the water (and from the air), when it dissolves. This results in the solution temperature being lower than the temperature of either the solid or the water.

C. Quantitative measurements on either of these systems would show interesting results.

  1. Temperature increases of the anhydrous $MgSO_4$ system varies directly with the amount of substance dissolved; that is, if the amount of $MgSO_4$ were doubled, the temperature rise in the system would double.

Investigation 12
Invention Discussion

A. Ask the students to review the observations they made in G. D. Part I. List the substance according to whether the temperature increased or decreased.

   1. State that solution processes that give off heat are called exothermic, and that solution processes that absorb heat are called endothermic.

B. Ask the students what the source of heat would be in an exothermic process. (Lead the discussion to the conclusion that the heat given off was tied up in the solute and solvent prior to the dissolving.)

   1. Repeat the procedure for the endothermic process. (The heat for this process must come from one or more elements of the environment, and is absorbed by the solute.)

C. Direct the attention of the students to the graphs of data for the quantitative solution process of anhydrous $MgSO_4$.

   1. Ask the students to deduce a relationship between the heat generated and the amount of $MgSO_4$. (This will be a linear, direct relationship.)

   2. Ask if the graph could be used to predict the amount of heat produced by a weight of $MgSO_4$ that would be beyond the range of the present graph. When the class has verbalized its understanding of the idea, summarize the discussion with the following invention statement.

D. Reactions involve changes in the total energy of the reacting substances. The amount of energy is directly proportional to the amount of reacting substances.

Appendix 9C

CAT Tests for LC-12

Name____________________
Section__________________
Date_____________________
Code______LC12-_________

1. Compare the amount of energy released in the following examples:
   (a) 50 grams of wood are burned
   (b) 150 grams of wood are burned

   Explain how you arrived at your comparisons.

2. A chunk of metal is heated to 100°C and plunged into a cup of water at 20°C. Compare the final temperatures in the following examples.
   (a) 50 gram chunk in 100 ml of water
   (b) 50 gram chunk in 200 ml of water
   (c) 100 gram chunk in 100 ml of water

   Explain how you arrived at your comparisons.

3. Compare the energy change of the metal chunk with the energy change of the water in the experiment described by question two.

Explain how you arrived at your comparisons.

Name____________________
Section__________________
Date____________________
Code LC12-

A chunk of ice is placed into a container of hot water at 60°C and allowed to melt.

1. Compare the amount of energy necessary to melt the ice in the following examples:
   (a) 5 grams of ice are melted
   (b) 15 grams of ice are melted

   Explain how you arrived at your comparisons:

2. Compare the final temperature of the water in the following examples:
   (a) 8 grams of ice are melted in 50 ml of water
   (b) 32 grams of ice are melted in 100 ml of water
   (c) 16 grams of ice are melted in 50 ml of water

   Explain how you arrived at your comparisons.

9C-4

3. Compare the energy change of the ice with the energy change of the water in the experiment described by question two.

Explain how you arrived at your comparisons.

Name______________________
Section____________________
Date______________________
Code_____LC12-___________

A candle flame is used to heat a beaker of water whose initial temperature is 20°C. The candle is weighed before and after it is used and the final temperature of the water is recorded.

1. Compare the amount of energy released in the following examples:
   (a) 3 grams of candle wax are used up
   (b) 9 grams of candle wax are used up

   Explain how you arrived at your comparisons.

2. Compare the final temperature of the water in the following examples:
   (a) 1 gram of candle wax used to heat 50 ml of water
   (b) 2 grams of candle wax used to heat 50 ml of water
   (c) 2 grams of candle wax used to heat 100 ml of water

   Explain how you arrived at your comparisons.

3. Compare the energy released by the candle with the energy change of the water in the beaker.

Explain how you arrived at your comparisons.

Description of CAT Tests, Rationale, Construction, Fit to LC Content and Grading Criteria for CATs in LC-12

The CAT tests for LC-12 were designed to ascertain the level of understanding possessed by students at various times during the learning cycle. The three questions on each of the forms of the CATs dealt with energy transfer in various systems and the relationships between energy transfer and a system's temperature change. These questions were consistent with the content goals of the learning cycle. To the extent that students showed an understanding of these ideas, they received scores in accordance with the general grading scale discussed in Chapter 2 of this report.

The first question on each form asked the students to judge and explain the amount of energy released (or gained) by two similar systems using different amounts of substance. The second and third questions were related to each other. The second question dealt with temperature changes in systems, while the third question asked the student to compare energy lost to energy gained between the components of the system.

Each question specifically called for an explanation to the initial response to the question. The question was graded as a single unit, however, with one number being assigned to the question. The three forms of the tests had some specific differences in response requirements. It is for this reason that the grading criteria are specified for each form of the test. Example responses will be listed for each form of the test. Copies of the CATs for LC-12 can be found in Appendix 9C.

FORM A - Question 1

Criterion 3: Example (b) releases three times as much energy as example (a). The explanation includes the idea that three times the amount of matter can store (or has) three times the energy.

Example Response: (b) is three times greater than (a). Each gram of wood, when burned, releases a certain amount of energy -- in (b) there is three times as much wood; therefore three times as much energy is released.

Criterion 2: The response is correct, as far as it goes, but it is incomplete. Qualitative comparisons and/or qualitative explanations fall into this category.

Example Response: (b) would release more energy than (a). Because there is more wood being burned in (b) and they are both the same kind of reaction so (b) would release more energy.

Criterion 1: No explanation, regardless of the initial response, or some specific misconception stated in the initial response or the explanation.

Example Response: The same amount of energy would be released for both (a) 50 g and (b) 150 g. Almost all wood has the same amount of energy. The wood would burn and release the same amounts of energy only (b) 150 g would burn longer.

Criterion 0: Blank paper or nonsense.

FORM A - Question 2

Criterion 3: The final temperatures, from highest to lowest would be (c), (a), (b). The explanation must take into account both the factors of weight of metal and volume of water.

Example Response: (b)'s temperature would rise the least, then (a), and (c) would have the highest temperature. In (c) there is more metal per ml of water. Ratios are: (c) = 1 1 to 1
(a) = 1/2 1 to 2
(b) = 1/4 1 to 4

Criterion 2: This would consist of not comparing all three systems but giving explanations of the ones compared. Complete comparisons with partial explanations would also fit this criterion.

Example Response: The final temperature of (c) will be the warmest, then (a), then (b). (c) has the least amount of space to release what heat it has.

Criterion 1: All or any part of the comparisons, correct or incorrect, with wrong explanations; correct comparisons with no explanations; or reference to the rate of heating or cooling.

Example Response: (a) will have a higher temperature than (b) because there is the same amount of metal and temperature is constant so the more water you have would cool it down. (c) would be about the same as (a).

Criterion 0: Blank paper or wrong comparisons with no explanation.

FORM A - Question 3

Criterion 3: Both energy changes are the same. The energy lost by the metal was gained by the water (i.e., an energy transfer occurred).

Example Response: The energy change would have to be equal or proportional. Because the energy gain should equal the energy lost. All the energy must be accounted for in one way or another.

Criterion 2: Both energy changes are the same (or an allusion to that), but the explanation is incomplete or unclear.

Example Response: The energy change of the metal chunk would be greater than that of the water. The metal had two chunks of 50 grams, one dipped in 100 ml and one in 200 ml. There is also a chunk that weighed 100 grams that was dipped in a 100 ml cup of water. There would be more energy between 50 grams and 200 ml.

Criterion 0: Blank paper or nonsense.

FORM B - Question 1

Criterion 3: (b) requires three times the amount of energy as (a). The explanation includes the idea that the energy required to melt ice is dependent on weight.

Example Response: It will take three times the energy to melt the 15 grams. It takes a certain amount of energy to melt 5 grams of ice. There are three times the amount of ice in 15 grams so it should take three times the energy.

Criterion 2: The response is correct, as far as it goes, but it is incomplete. Qualitative comparisons and/or qualitative explanations fall into this category.

Example Response: More energy is necessary to melt 15 grams of ice. Energy is added to the ice to melt. Therefore, more energy would have to be added to the larger amount of ice.

Criterion 1: No explanation is given, regardless of the initial response, or a misconception is stated.

Example response: About the same amount needed for both. The amount of a substance is not always dependent on how much energy is needed unless there is a large difference in the amount.

Criterion 0: Blank paper or nonsense.

FORM B - Question 2

Criterion 3: Temperature of (b) equals temperature of (c), and the temperature of (a) is greater. The explanation must include both factors of the weight of ice and the volume of water.

Example Response: 16 g of ice in 50 ml of water will be twice as cold as 8 g in 50 ml. 32 g of ice in 100 ml will be the same temperature as 16 g in 50 ml. 16 g in 50 ml is twice as cold as 8 g in 50 ml because you have twice the amount of ice in the same amount of water. 32 g in 100 ml is the same temperature as 16 g in 50 ml because the ratio is the same.

Criterion 2: This is satisfied by not comparing all three systems but giving correct explanations of the ones compared; or if explanations are incomplete.

Example Response: The temperature of (c) will be lower than (a) and equal to (b). Since (c) has more ice being melted, more energy is transferred causing a greater change in temperature.

Criterion 1: All or any part of the comparisons right or wrong with wrong explanations; correct comparisons with no explanation; or arguments from the standpoint of rates of melting.

Example Response: (b) is hottest, (a) is second hottest, and (c) is coolest. When you put ice in a container, the more volume taken up means cooler temperature. The more water and less ice, then cooler temperature.

Example Response: (a) is the warmest; (b) and (c) would have about the same temperature, but colder than (a). If (b) was reduced, it has the same ratio as (c). So (b) and (c) are the same, just about. (a) has less ice than (b) and (c), to the amount of water. (a) will melt faster than (b) and (c) and (a) will have extra time to get warmer than (b) and (c).

Criterion 0: Blank paper or nonsense.

FORM B - Question 3

Criterion 3: Both energy changes are the same. The energy lost by the water was gained by the ice (i.e., an energy transfer occurred).

Example Response: The ice should have gained the same amount of energy as the water lost. To melt the ice the water had to give up some of its energy to speed up the movement of the water particles in the ice. So, every bit of the energy given off by the water should have been taken in by the ice.

Criterion 2: Both energy changes are the same (or an allusion to that) but the explanation is incomplete or unclear.

Example Response: The water will drop in temperature and the ice will increase in temperature. Because you add something cold to the water and something hot to the ice.

Criterion 1: The first response is correct but there is an incorrect explanation; the first response is correct but there is no explanation; the first response is incorrect, and there is no explanation or an incorrect explanation; or allusion to energy transfer is made but no indication is given of equality of energy.

Example Response: The more ice you have melted, the colder the water is going to be. The more ice means the higher level of slow moving molecules there are. When ice is melted in water, the temperature will decrease because ice has a lesser temperature than water. The slow moving ice molecules have an energy interaction with the moderate moving water molecules. When the ice is melted, the ice molecules slow down the water molecules.

Criterion 0: Blank paper or nonsense.

FORM C - Question 1

Criterion 3: Example (b) releases three times as much energy as example (a). The explanation includes the idea that three times the amount of matter can store (or has) three times the energy.

Example Response: Three times as much energy is released in (b) as in (a), as long as the type of wax is the same. X amount of energy is released when 3 grams of wax are used up. 3X amount of energy is released when 9 grams of wax are used up.

Criterion 2: The response is correct as far as it goes but it is incomplete. Qualitative comparisons and/or qualitative explanations fall into this category.

Example Response: There was more energy used in (b) than there was in (a). There was more of (b) gone so it was burning longer and releasing energy all the while.

Criterion 1: No explanation, regardless of the initial response, or some specific misconception stated in the initial response or the explanation.

Example Response: More energy required for the 9 grams. When there's more substance to use up, more energy is required to use it up, because the 3 grams takes less time.

Criterior 0: Blank paper or nonsense.

FORM C - Question 2

Criterion 3: Final temperature of (a) and (c) are equal and less than the final temperature of (b). The explanation must include consideration of both the weight of wax and the volume of water.

Example Response: (b) would be the warmest while (a) and (c) would be the same. More energy was used in (b) to heat the same amount of water as in (a), so (b)'s water should be warmer. (c) should be the same as (a) because while the amount of water doubles, so does the amount of wax. It should even out.

Criterion 2: This score is given for not comparing all three systems, but giving correct explanations of the ones compared; or if explanations are incomplete.

Example Response: Both (a) and (c) would have the same temperature. (b) would be more hotter than (a) and (c). (c) is almost the same thing as (a) but it just doubled. On (b) there is more candle wax to burn so the water would be hotter.

Criterion 1: All or any part of the comparisons, right or wrong, with wrong explanations; correct comparisons with no explanation; or arguments made from the standpoint of rate of heating.

Example Response: (b) will have the highest final temperature. (a) and (c) will probably have similar final temperatures. The more energy per unit of water, the higher the temperature of the water. On (a) and (c) the activation energy is greater and with the same energy it won't get as hot.

Criterion 0: Blank paper or nonsense.

FORM C - Question 3

Criterion 3: Both energy changes are the same. The energy lost by the candle was gained by the water (i.e., an energy transfer occurred).

Example Response: They should be the same. The energy is not made or lost. It is transferred back and forth from the candle to the water.

Criterion 2: Both energy changes are the same (or an allusion to that), but the explanation is incomplete or unclear.

Example Response: The energy released by the candle is in the form of heat energy. The water converts this heat energy to kinetic energy and the average kinetic particles of the water increase. The heat released by the burning of the candle obviously is transferred to the water to increase the temperature of the water since the temperature rises).

Criterion 1: The first response is correct but there is an incorrect explanation; the first response is correct but there is no explanation; the first response is incorrect and there is no explanation or an incorrect explanation; or allusion to energy transfer is made but no indication is given of equality of energy.

Example Response: The more energy released by the candle the higher the temperature of the water would be. The candle released energy so the water particles move around faster and heat up. The more energy released by the candle, the hotter the water gets so the temperature goes up.

Criterion 0: Blank paper or nonsense.

Appendix 9D
BAR Written Comments

BAR Written Comments

LC- 12 CLASS 111 N = 23 , 22 with comments

Sequence, EGI

	+	0	-	Comments
Lab	13		2	
Discussion	1		1	students continue to express dislike of taking CAT
Demo	7			
Questions			1	
Problems				
Readings			5	
Lecture				
	21		9	

	#	Comments
I'm Confused	2	
Activities Not Logical		
Too fast		
Too slow	1	
I Understand	1	
I Like	2	
I Don't Like	1	
Activities Are Logical		
	7	

Quotes: "I thought that starting out with the interesting demonstration made most people more interested. The labs were also fairly interesting, and this made me really want to understand endo- and exothermics."

"I like this lab no more or no less than any other one. I feel it was done in about the best order possible. Some review on motor heat, however, would be helpful. I didn't fully understand it. I just hope we get some type of review to sum everything up and pull it all together."

"Things seem a little bit complicated but not difficult. I mean they are not easy to understand. So far I'm not at my best, but I like the topic."

BAR Written Comments

LC- 12 CLASS 114 N = 14 , 14 with comments

Sequence - EIG

	+	0	-	Comments
Lab	4		1	
Discussion	2			
Demo	9			
Questions			2	
Problems			1	
Readings			6	
Lecture				
	15		10	

	#	Comments
I'm Confused	3	
Activities Not Logical	2	
Too fast		
Too slow		
I Understand		
I Like	2	
I Don't Like		
Activities Are Logical		
	7	

Quotes: "I like the reading about oily rags the least. It seems to go in a roundabout way and used words I didn't know. The questions were very hard."

"Parts I didn't like was you never told us why the two solid white crystals caused heat to drop."

"I liked the volcano demo the best. That was the kind of thing I expected to be doing in chemistry everyday. I thought it was really neat. I disliked the questions asked before we had even discussed the answers, like one question over endo- and exothermic reactions."

"Liked volcano demonstration. Did not like reading and lesson discussing lab being done before lab! If the concept was taught in a more straight forward manner, I am absolutely positive that it would be better understood by everyone."

9D-4

BAR Written Comments

LC- 12 CLASS 116 N = 22 , ______ with comments

Sequence - GEI

	+	0	-	Comments
Lab	6			
Discussion			1	comments about repetitiveness of tests
Demo	8		1	
Questions			2	
Problems			3	
Readings			4	
Lecture				
	14		11	

	#	Comments
I'm Confused	1	
Activities Not Logical	2	
Too fast	2	
Too slow		
I Understand	1	
I Like	5	
I Don't Like		
Activities Are Logical	3	
	14	

Quotes: "I feel we should have learned certain terms like endothermic and exothermic before we started any of the labs. We have not learned a whole lot in this activity."

"There are definite problems with this sequence. The order was bad. We were asked questions that we couldn't answer (exo-, endothermic) and learned about them afterwards. There was also no sufficient explanation of why things performed as they did. The labs were good. They were at least interesting, and we were not as rushed in them as usual."

"I thought the order of the activities was perfect."

9D-5

"I disliked the fact that during the labs we don't know what we're doing or the purpose for it until after it's over."

"I disliked having to answer questions before the new information is taught. I think we should have reading first and then do labs. We would know what to look for then."

"This was a good order to go in."

"I think the order was mixed up. We should have discussed first and done the readings then the labs and demo's. I think I would have learned better and understood more. We also went too fast without enough explanation."

"Also, these activities (and this one is no exception) always seem so mixed up."

"I liked everything we did except I think I would have understood more if we would have had a discussion after the first lab, demonstration, and reading and then had another one at the very end."

"Activities seem mixed up and not related to each other."

BAR Written Comments

LC- 12 CLASS 121 N = 23 , 15 with comments

Sequence - Control
GIE

	+	0	-	Comments
Lab	7			
Discussion	3		2	Need more discussion
Demo	3			
Questions			2	
Problems	1		1	
Readings	1		3	
Lecture				
	15		8	

	#	Comments
I'm Confused	4	
Activities Not Logical		
Too fast		
Too slow	1	
I Understand		
I Like	2	
I Don't Like		
Activities Are Logical		
	7	

Quotes:

BAR Written Comments

LC- 12 CLASS 122 N = 19 , 16 with comments

Sequence - IGE

	+	0	-	Comments
Lab	7			
Discussion	1			
Demo	2			
Questions			2	
Problems	1		2	
Readings	1			
Lecture				
	12		4	

	#	Comments
I'm Confused	3	
Activities Not Logical		
Too fast		
Too slow		
I Understand	1	
I Like	2	
I Don't Like		
Activities Are Logical		
	6	

Quotes: "I like all of the things we are doing, but I would like to have more in-depth class discussions."

"It wasn't that boring. I'm just not really sure what we're studying. I can't answer the reading questions even though I try. I can't understand the concept that we're learning now. Maybe I could if I really, really tried, but I'm not that interested in it. I listen in class and take notes and think I understand it but when we get readings, I can't do the questions. I could do some extra reading and come in for help but I don't."

"I don't understand what is going on; that's the part I dislike. If I understood it, I would like it. I like the labs."

"I didn't like the way the last Investigation didn't have many questions to help clarify the questions."

"I think I understand everything but I'm not sure what the main idea is (what is the main concept that we're supposed to be learning)."

BAR Written Comments

LC- 12 CLASS 125 N = 22 , 17 with comments

Sequence - IEG

	+	0	-	Comments
Lab	6			
Discussion	1			
Demo	1			
Questions			2	
Problems				
Readings			2	
Lecture			1	
	8		5	

	#	Comments
I'm Confused	5	
Activities Not Logical		
Too fast	2	
Too slow	1	
I Understand	3	
I Like	3	
I Don't Like	1	
Activities Are Logical		
	15	

Quotes: "The unit has been relatively easy compared to the previous units studied. I basically understand the material, however, it is hard to understand what I am expected to know, and what I will be tested over."

"The activity itself was easy enough but I don't know what its' purpose is. Whenever we learn how to work new problems, we go too fast. I almost understand and then we go on to something totally unrelated."

"I like learning why some reactions produce 'cold' or 'heat'. However, all I have learned is their names; endothermic and exothermic."

9D-10

Appendix 10A

Student Materials for LC-14

INVESTIGATION 14

Name______________________

Section____________________

GATHERING DATA
ARRHENIUS SOLUTIONS

A. In the laboratory there are two solutions and two solids in labeled containers. Be sure that you are careful to avoid contaminating the solutions and solids, when you are performing tests on them. Test each compound as a solid and as a solution with litmus paper and for conductivity.

B. Classify the compounds into acids and bases.

Acids

Bases

C. Look carefully at the formulas for the acids and the bases. Make a hypothesis of the characteristics that make a substance an acid or a base.

D. Using your hypothesis predict whether the following compounds are acidic or basic.

Table 14-1

Compounds	Predictions	Results of Conductivity Tests	Reaction to Litmus Paper
NH_4OH			
H_3BO_3			
HNO_3			
$Ba(OH)_2$			
KOH			
$HC_2H_3O_2$			
H_2SO_4			
$Ca(OH)_2$			
HBr			

E. In Table 14-1 you made predictions about which compounds were acids and which were bases. You may now test these predictions in the laboratory. List the tests you perform and the results in Table 14-1.

THE IDEA
QUESTIONS

Name____________________
Section____________________

1. Is the presence of water necessary for a substance to exhibit acid or base characteristics? If so, what effect must water have on a substance to make it display those characteristics? If not, why not?

2. On the basis of your study, give complete definitions for acids and bases, including the criteria necessary to make the acid or base exhibit its characteristics.

EXPANDING THE IDEA
METALS IN ACIDS

Name____________________
Section____________________

A. Write the chemical equation for the reaction of magnesium and hydrochloric acid.

B. What type of chemical reaction is this?

C. Equipment

1 - eudiometer
1 - 25 x 150 mm test tube
1 - #4, one hole stopper
1 - right angle glass bend
1 - U bend glass tube
1 - 12 in. length of rubber tubing
1 - 600 ml beaker
1 - ring stand with clamp for eudiometer

Set up your laboratory apparatus to collect the gas by displacement of water. You will read the volume of gas collected after each minute for a period of five minutes. First add the acid to the test tube. When ready to collect the gas, add a 40 cm length of magnesium ribbon to the test tube. Each group will test three different acid solutions according to your teacher's instructions.

D. In Table 14-2 record the solutions your group will be testing and your data from section C.

Table 14-2

10 ml of Various Acids		Volume of gas after			
	1 min.	2 min.	3 min.	4 min.	5 min.

E. Record the class data in Table 14-3

Table 14-3

		Volume of gas after			
Acid Solution	1 min.	2 min.	3 min.	4 min.	5 min.
0.1M HCl					
Average					
0.1M $HC_2H_3O_2$					
Average					
0.2M HCl					
Average					
0.2M $HC_2H_3O_2$					
Average					
0.3M HCl					
Average					

Table 14-3

Acid Solution	1 min.	Volume of gas after 2 min.	3 min.	4 min.	5 min.
0.3M $HC_2H_3O_2$					
Average					
0.4M HCl					
Average					
0.4M $HC_2H_3O_2$					
Average					

QUESTIONS

1. Does the concentration of the acid solution affect the reaction rate? Explain.

2. Compare the reaction of magnesium with .4M HCl to the reaction of magnesium with .4M $HC_2H_3O_2$.

EXPANDING THE IDEA
READING 14a

IONS IN EQUILIBRIUM

This reading will concentrate on the behavior of two substances in water solution: ammonium chloride (NH_4Cl) and boric acid (H_3BO_3). Both substances are soluble in water, even though ammonium chloride will dissolve to a greater extent than boric acid. (At 25°C, the solubility of ammonium chloride is 25g/100ml, and the solubility of boric acid is 5.2g/100ml.) In the dissolving process the compounds ionize. Ammonium chloride's ionization can be represented by:

$$NH_4Cl \longrightarrow NH_4^+ + Cl^-.$$

The ionization of boric acid has several possibilities, such as:

$$H_3BO_3 \longrightarrow H^+ + H_2BO_3^-$$

$$H_3BO_3 \longrightarrow 2H^+ + HBO_3^{2-}$$

$$H_3BO_3 \longrightarrow 3H^+ + BO_3^{3-}$$

A saturated solution (at 25°C) of ammonium chloride will conduct electricity (light bulb apparatus). This fact is not surprising in light of the model for the formation of charged particles in the solution upon dissolving. By contrast, a saturated solution (at 25°C) of boric acid will not conduct electricity (light bulb apparatus). An immediate thought might be that boric acid does not ionize. Certainly the conductivity test would support that idea, but recall that the litmus test shows that ionization does occur. Since the litmus changed from blue to pink, one or more of the ionization equations written above would be reasonable (excess H^+ in the system).

Why is the boric acid solution non-conductive? Among the possible answers to this question is the argument that boric acid is less soluble than ammonium chloride; therefore, less ions will be produced in the boric acid solution. Let's test this argument, using the information that we have. The 5.2g of H_3BO_3 that will dissolve, under the conditions previously described, is approximately equal to 0.08 moles of boric acid. Since we know that 25g of NH_4Cl (.47 moles) will dissolve, under these conditions, we can be assured that 4.24g (0.08 moles) of ammonium chloride will dissolve in 100ml of water! We already know that such a boric acid solution will not conduct electricity. However, an ammonium chloride solution, containing the same number of moles of solute (0.08 moles), will conduct.

What conclusion can be drawn from this test? The most apparent conclusion is that equal numbers of the two types of molecules (equal moles) do not produce equal numbers of ions, when dissolved in water. Furthermore, the ammonium chloride solution contains the greater number of ions.

Assume that all of the ammonium chloride in our present example ionized. Observe (ionization equation above) that two ions--one ammonium ion and one chloride ion--are produced for each molecule of ammonium chloride that ionizes. When the 0.08 moles of ammonium chloride dissolve, therefore, we would obtain 0.16 moles of ions in the solution--enough to allow for "light bulb" conductivity. Applying this to the boric acid solution, we must conclude that the first ionization equation for boric acid (above) is the only one that is reasonable, and even that does not happen for all of the H_3BO_3 that dissolves! (Do you see why?)

Now, let's attempt to build a model (logical explanation) for these observations on boric acid. We can start by considering unionized boric acid molecules in the solution. Recall ("H_2O vs. The Solute") that water is a vigorous solvent, constantly "tugging" at the boric acid molecules. As a result of this pulling effect, some molecules ionize into H^+ and $H_2BO_3^-$ ions. We have seen that if this had happened to all the boric acid molecules the solution would have conducted electricity. Since it doesn't conduct, this ionization process must "stop" somewhere short of total ionization. Reasonably, we could not expect the solution to reach a point where some sort of "stop signal" was given, after which there was no more activity. We would, instead, expect the vigorous pulling action of water to continue indefinitely because of the constant, random motion of the water molecules. This constant, random motion would continue to ionize boric acid molecules, but it would also permit H^+ and $H_2BO_3^-$ ions to move near each other, attract, and recombine into boric acid molecules. As the number of ions increases from the action of the water, the chances of ions recombining to form boric acid molecules also increases. We can conceive of a point in this interaction when the number of molecules breaking up, in a given time, equals the number of ions recombining. At this point, which has been referred to before as dynamic equilibrium, we see no net change in the number of ions or the number of boric acid molecules in the system.

Is it possible that the ammonium chloride solution does not totally ionize? Yes! The only thing we know for certain, from our discussion here, is that the ammonium chloride solution ionizes to a much greater extent than does the boric acid solution. We could reasonably assume that the ammonium chloride solution also establishes a dynamic equilibrium similar to that of the boric acid solution. This idea could be extended to all water solutions.

Whether a substance ionizes a little, a lot, or none at all is a matter whose importance depends on the system being considered. For example, the small amount of ionization in water can be ignored, when "light bulb" conductivity is being considered. On the other hand, the ionization of water becomes an important consideration in the explanation of the acid-base characteristics of aluminum chloride or calcium oxide solutions.

EXPANDING THE IDEA
READING 14b

THOSE MIGHTY ACIDS

The stereotyped strong acid in the minds of many individuals is one which will burn through a desk top in a matter of seconds releasing great clouds of bilious smoke. After the acid has devoured the wood, it drips to the floor only to destroy the floor beneath. Indeed, some acids are quite powerful in their action upon various substances. For instance, gold was considered to be a purely noble metal until aqua regia (royal water) came along. This solution of concentrated nitric and hydrochloric acids was so named because it was found to actually dissolve the royal metal, gold. Sulfuric acid, sometimes called the "King of Acids" (it is the most widely used industrial acid), is an excellent dehydrating agent. It's reaction with common table sugar, sucrose, is a fine example of how it readily draws water out of a substance. The once white crystal is transformed into a black carbon mass within a few seconds when subjected to a concentrated solution of this acid.

Maybe you have wondered why some acids display such dramatic properties while others may seem to be virtually unreactive. Consider with me the effect on our bodies if common ascorbic acid (vitamin C) from citrus fruit were as reactive as aqua regia. Once injested, imagine its attack upon sensitive throat linings. The fact is, however, that ascorbic acid is a weak acid, as are many other important acids necessary for the maintenance of human life. Again, why is there such a marked difference in their chemical behaviors?

Historically, chemists have not answered this question with the same ease we might on paper. Much labor has gone into understanding not only the reactivity of acids (as well as bases), but also the composition of such substances. Chemical knowledge has not come over-night. The French chemist, Antoine Lavoisier (1743-1794), often called the father of modern chemistry, has stated that an acid had to contain oxygen. This assumption certainly proves true with nitric acid-HNO_3-and sulfuric acid-H_2SO_4, but not with hydrochloric acid-HCl. We may be tempted to say to Mr. Lavoisier, "Look at the formula-HCl-there is no oxygen in it!" (This illustrates how much we can take for granted in our modern laboratories.)

The oxygen theory of acids prevailed until Humphry Davy (1778-1829), an Englishman noted for his discoveries of sodium, potassium, calcium, barium, magnesium, and strontium, questioned the Lavoisier hypothesis. Through investigation of muriatic acid (as HCl was then known), Davy determined that hydrogen and a gas he named chlorine were the components of this substance. Having refuted the previous hypothesis, he proposed a new hypothesis stating that acids were "particular compounds in which the hydrogen can be replaced by metals." This sounds more like our current definition, but we are not finished with our historical excursion yet.

A Swede, Svante Arrhenius, refined the model a bit further in 1884 while studying at the University of Uppsala. He proposed, after analyzing electrical conductivity in solutions, that the dissolved substance must break up into ions. Therefore, an acid now became regarded as a substance which released H^+ ions in solution. Similarly, a base was a substance which released OH^- ions. (Although Arrhenius' theory was not well accepted when first set forth, it earned him the Noble prize in chemistry 19 years later.)

Why is the strength of one acid different from that of another? Sulfuric acid ionizes more readily than boric acid. It is not that boric acid is not soluble in water; it is! Something else must be the determining factor. Compare the sulfate ion with the borate ion. Which carries the greater charge? Which ion resists dissociation from hydrogen to a greater extent?

Sulfuric acid, for all practical purposes, ionizes completely in its first dissociation, $H_2SO_4 \longrightarrow H^+ + HSO_4^-$ (that is, nearly every molecule undergoes this reaction). Furthermore, about one out of 10 of the remaining bisulfate ions dissociate again, $HSO_4^- \longrightarrow H^+ + SO_4^{2-}$. On the other hand, timid boric acid produces less than one dissociation in forty thousand molecules at room temperature in aqueous solution. (This property contributes well to its use as an eye wash.)

The degree of dissociation for an acid or a base is expressed through what is called the dissociation constant, designated K_A for an acid and K_B for a base. (You may ask, why K? Remember °C stands for Celsius. K seems to be next on the list of alphabetical possibilities.) K_A for the first dissociation of carbonic acid is 4.30×10^{-7} at room temperature ($H_2CO_3 \longrightarrow H^+ + HCO_3^-$). If the molar concentration of the H^+ ion is multiplied by the molar concentration of the bicarbonate ion, and the product divided by the molar concentration of molecular H_2CO_3 remaining in solution, one may obtain this constant.

$$\frac{[H^+] \times [HCO_3^-]}{[H_2CO_3]} = K_A$$

Examine tables 1 and 2. Order the acids and bases from weakest (least ionized) to strongest (most ionized).

TABLE 1

Equilibrium Constants for some acids in aqueous solutions

Compound	Formula	T°C	K_A
Acetic acid	$HC_2H_3O_2$	25	1.76×10^{-5}
Arsenic acid	H_3AsO_4	25	5.62×10^{-3}
Boric acid	H_3BO_3	25	5.79×10^{-10}
Carbonic acid	H_2CO_3	25	4.30×10^{-7}
Hydrochloric	HCl	25	very large
Hydrocyanic	HCN	25	4.93×10^{-10}
Nitric acid	HNO_3	25	very large
Nitrous acid	HNO_2	25	4.6×10^{-4}
Phosphoric acid	H_3PO_4	25	2.3×10^{-2}
Sulfuric acid	H_2SO_4	25	very large

TABLE 2

Equilibrium Constants for some bases in aqueous solutions

Compound	Formula	T°C	K_B
Ammonium hydroxide	NH_4OH	25	1.79×10^{-5}
Calcium hydroxide	$Ca(OH)_2$	25	3.74×10^{-3}
Hydroxylamine	NH_2OH	20	1.07×10^{-8}
Lead hydroxide	$Pb(OH)_2$	25	9.6×10^{-4}
Potassium hydroxide	KOH	25	very large
Silver hydroxide	AgOH	25	1.1×10^{-4}
Sodium hydroxide	NaOH	25	very large
Zinc hydroxide	$Zn(OH)_2$	25	9.6×10^{-4}

I14 Form Experiment
Change in Lesson Control

GATHERING DATA - READING

Oxalic acid ($H_2C_2O_4$) is a white, crystalline solid. When it is tested with litmus paper, there is not a reaction. The solid $H_2C_2O_4$ will not conduct a current. However, if a $H_2C_2O_4$ solution is tested, litmus paper turns blue to pink and the solution conducts a current.

When solid magnesium hydroxide $[Mg(OH)_2]$ a white powdery solid, is tested, it does not light the bulb or react the litmus paper. If a solution of $Mg(OH)_2$ is tested, the litmus paper turns pink to blue and the solution does not conduct a current.

Solutions of hydrochloric acid (HCl) and sodium hydroxide ($NaOH$) are tested for conductivity. Both of these solutions will conduct a current. When HCl is tested with litmus paper, it turns from blue to pink. $NaOH$ turns litmus from pink to blue.

The following compounds are tested with litmus paper and for conductivity. The results obtained are listed in the table.

Compounds	Litmus paper	Conducts
NH_4OH	pink to blue	yes
H_3BO_3	blue to pink	no
HNO_3	blue to pink	yes
$Ba(OH)_2$	pink to blue	yes
KOH	pink to blue	yes
$HC_2H_3O_2$	blue to pink	yes
H_2SO_4	blue to pink	yes
$Ca(OH)_2$	pink to blue	yes
HBr	blue to pink	yes

6

Investigation 14
Invention Reading

If you analyze the formulas for the compounds in the data reading for this investigation, you will notice that all of the compounds contain the element hydrogen. Most, though not all, of the compounds also contain oxygen. Aside from these two elements, however, there is not real generalizable pattern in the other elements contained in the compounds.

Since you need to develop reasoning to explain the relationship between formula characteristics and acid-base properties, it would be good to examine the information given as it relates to the presence of hydrogen and oxygen in the compounds. You will notice that all the compounds that are acidic (turn blue litmus to pink) contain hydrogen. Furthermore, the presence of oxygen is not essential to an acid, as indicated by the HCl and HBr examples. The other key piece of information regarding acids is their conductivity in water solution. In Investigation 13 you found that the conductivity of a solution is dependent on the presence of ions in the solution. All the acids listed have water solutions that conduct electricity, except for boric acid, so it is logical to conclude that the acids ionize in water.

In order to obtain the consistent litmus test indications there will have to be a consistency in ionization of the compound. You may think that that is a bold statement, but notice that, in solid form, there is no change in litmus paper and there is no conduction of electricity. The only way that all of the acid substances listed could ionize consistently would be for one of the ions to be the hydrogen ion (H^+). This implies that the hydrogen ion is responsible for the acid characteristics of the substances.

We have noted that not all of the acid substances contain both hydrogen and oxygen. This is not the case, however, with the base substances. Each of them contain oxygen and hydrogen; in fact, the arrangements of these elements in the base compounds makes it convenient to assume that those compounds ionize into some positive ion and the negative hydroxide ion.

If we assume that the hydroxide ion does for bases what the hydrogen ion does for acids, we can make the following summary statement regarding acids and bases:

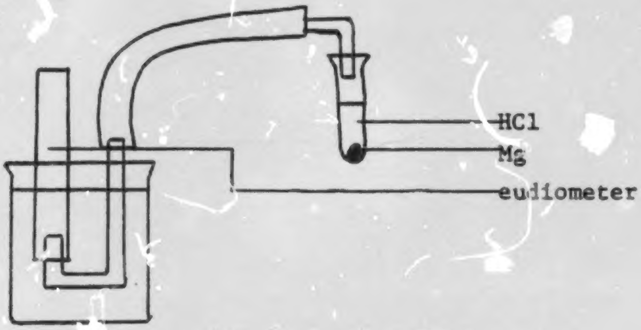
> Acids are compounds, containing hydrogen, that release H^+ ions in water solution; and bases are compounds, containing hydroxide, that release OH^- ions in water solution.

Expanding the Idea
Reading 14
Metals in Acids

Magnesium reacts with hydrochloric acid according to the following equation:

$$Mg + 2HCl \longrightarrow MgCl_2 + H_2.$$

The hydrogen gas which is released can be collected in a gas measuring tube (a eudiometer) using the apparatus shown in figure 1.



A eudiometer is filled with water and inverted into a beaker of water. A glass tube connected to a reaction test tube, is mounted below the mouth of the eudiometer. A measured amount of Mg is placed in the test tube. A solution of .1 M HCl is added and the evolved gas is collected in the eudiometer. The amount of gas collected is measured every minute for five minutes. The faster the gas is released (i.e. the more vigorous the reaction), the more gas is collected in the eudiometer. Table one contains the data collected when .1 M, .2 M, .3 M, and then .4 M HCl are used.

Table 1

Acid Solutions	Volume After 1 Min.	2 Min.	3 Min. (in ml)	4 Min.	5 Min.
.1M HCl	8.7	13	14.8	15.7	16.2
.2M HCl	14	21.2	24	25.2	25.9
.3M HCl	27	35	37	38.1	39
.4M HCl	37.5	46	48.2	49	49.6

In comparing the volumes of hydrogen gas evolved by different concentrations of HCl it can be seen that the more concentrated the HCl the faster the evolution of gas (i.e. the more vigorous the reaction).

Magnesium reacts with other acids besides hydrochloric acid. This logically leads one to hypothesize that the hydrogen ion (H^+) is responsible for the reaction and that consequently the greater the H^+ concentration the more vigorous the reaction. If this is so, we ought to see the same pattern for other acids as we see for HCl.

Table two contains the data collected when acetic acid ($HC_2H_3O_2$) is used instead of HCl.

Table 2

Acid Solution	Volume After 1 Min.	2 Min.	3 Min.	4 Min.	5 Min.
.1M $HC_2H_3O_2$	2	3	3.5	4	4.3
.2M $HC_2H_3O_2$	9.7	15.7	18.7	20.4	21.4
.3M $HC_2H_3O_2$	14.5	25	30	32.2	34.2
.4M $HC_2H_3O_2$	15	28	34	37.5	39.7

In examining these data it can be seen that the more concentrated the acetic acid the more vigorous the reaction. This is the same result noticed for HCl. However, if the two sets of data are compared (table 1 vs. table 2) a striking difference is apparent; the reactions with HCl are more vigorous than those with $HC_2H_3O_2$. This can be seen, for example, if you compare the .4 M HCl after 5 minutes with the .4 M $HC_2H_3O_2$ after 5 minutes.

If both acids are the same concentration how would you account for this difference? One way is to say that if the H^+ concentration accounts for the reaction then the H^+ concentration for .4 M HCl is greater than the H^+ concentration for .4M $HC_2H_3O_2$. This still leaves us with a question. How could .4 M HCl release more H^+ than the same concentration of $HC_2H_3O_2$? Readings 14a and 14b will help to answer this question.

Appendix 10B

Teacher Materials for LC-14

INVESTIGATION 14
ARRHENIUS SOLUTIONS
TEACHER NOTES

A. The responses to the two Idea questions should contain the following ideas:

1. The presence of water is essential to the exhibition of acid and base characteristics. The effect of the water is to break the acids and bases into ions, and these ions interact with the indicator in the litmus paper. (It should be noted that many students will not have made the connection between the indication and the type of ion responsible.)
2. a. An acid is a substance, containing hydrogen, which dissolves and ionizes in water to produce hydrogen ions. The water solution will conduct electricity and will change litmus paper from blue to pink.
   b. A base is a substance containing hydroxide, which dissolves and ionizes in water to produce hydroxide ions. The water solution will conduct electricity and will change litmus paper from pink to blue.

THE IDEA DISCUSSION:

B. In this discussion the teacher will begin with the student responses to the two questions and work toward the development of the Arrhenius definitions for acids and bases.

1. Ask for student responses to question 1. The attention of the class should be focused on the ionization process (as evidence by conductivity tests). Students may need to be reminded that water seems to exhibit both positive and negative electrical attraction characteristics (introduced in PROPERTIES OF IONIC SUBSTANCES).

2. The teacher can ask for volunteers to give their responses to question 2. The first people to answer may omit some important factors, but these can be filled in by other student additions. List the definitions on the board.

   Lead the discussion to the idea that the acid solutions have hydrogen ions in common and that basic solutions have hydroxide ions in common.

3. The criteria proposed within question 2 may be drawn from the written exercises and laboratory findings in "Gathering Data." At least the following points are expected to surface during class interaction:

   a. the substance must be in an aqueous solution;
   b. the substance must ionize in solution (usually conducting electricity);
   c. the solution must change litmus paper;

B. A question should arise as to the non-conductive behavior of boric acid. The teacher may wish to heat a saturated solution to test with a conductivity apparatus. Since the light will glow dimly, its extent of ionization may be discussed in contrast with the much greater ionization of hydrochloric acid. The acidic indication of boric acid to litmus paper should also be pointed out.

C. The conceptual invention should be Arrhenius acids are compounds that release H^+ ions in water solution. Solid acids are compounds containing H^+ ion. Bases are compounds that release OH^- ions in water solution. Solid bases are compounds containing OH^- ions.

I14 Form Experiment
Change of Lesson Control

GATHERING DATA - TEACHER 1

Oxalic acid ($H_2C_2O_4$) is a white, crystalline solid. When it is tested with litmus paper, there is not a reaction. The solid $H_2C_2O_4$ will not conduct a current. However, if a $H_2C_2O_4$ solution is tested, litmus paper turns blue to pink and the solution conducts a current.

When solid magnesium hydroxide $[Mg(OH)_2]$ a white powdery solid, is tested, it does not light the bulb or react the litmus paper. If a solution of $Mg(OH)_2$ is tested, the litmus paper turns pink to blue and the solution does not conduct a current.

Solutions of hydrochloric acid (HCl) and sodium hydroxide (NaOH) are tested for conductivity. Both of these solutions will conduct a current. When HCl is tested with litmus paper, it turns from blue to pink. NaOH turns litmus from pink to blue.

The following compounds are tested with litmus paper and for conductivity. The results obtained are listed in the table.

Compounds	Litmus paper	Conducts
NH_4OH	pink to blue	yes
H_3BO_3	blue to pink	no
HNO_3	blue to pink	yes
$Ba(OH)_2$	pink to blue	yes
KOH	pink to blue	yes
$HC_2H_3O_2$	blue to pink	yes
H_2SO_4	blue to pink	yes
$Ca(OH)_2$	pink to blue	yes
HBr	blue to pink	yes

Investigation 14
Invention Lecture

A. Begin by stating and writing on the board "acids are compounds, containing hydrogen, that release H^+ ions in water solution; bases are compounds, containing hydroxide, that release OH^- ions in water solution."

B. Using a data table that has been filled out (either from the demonstration of gathering data or from the teacher presentation), go through listing all the acid formulas together and all the base formulas together.

C. Point out that most solutions of these compounds conducted electricity. Bring in the ideas developed in Investigation 13 about the ions of a solution permitting the conduction of electricity.

D. Referring students to the lists of compounds, point out that hydrogen is the only element that is common to all the acids.

   1. Write out ionic products for each of the acids to show that each produces H^+ in solution (e.g., $HCl \longrightarrow H^+ + Cl^-$).

   2. Refer the students back to the original statement in this lecture.

E. Referring students to the lists of compounds, point out that the bases seem to be composed of some positive ion attached to one or more OH^- ions.

   1. Write out ionic products for each of the bases to show that each produces OH^- ions in solution (e.g., $NaOH \longrightarrow Na^+ + OH^-$).

   2. Refer the students back to the original statement in this lecture.

Expansion for LC 14 - Form less on Control

Teacher 1 (lecture) E

Teacher describes putting Mg metal in acid and writes the equation on the board. Teacher then discusses collecting the H_2 gas and the rate of collection as a measure of reaction vigor.

Teacher then describes the apparatus used to collect the H_2 gas and presents the data array on board or overhead (use array on page 10B-6).

Teacher uses data to show the effect of concentration on reaction vigor. Teacher then develops the idea that the larger the concentration of H^+ the greater the reaction vigor. Teacher then rhetorically asks why different acids of the same concentration react differently.

Using R14a as an outline introduce the idea of equilibrium to illustrate that different substances don't ionize completely and use this to suggest that the H^+ concentration of some acids is lower than others, thus accounting for the different reactivities. Then use the outline of R14b to invent K_A and the strong/weak concept. Finally present a table of K_A, K_B values and discuss them.

Sample Results for Expanding the Idea

Acid Solutions	Volume After 1 Min.	2 Min.	3 Min.	4 Min.	5 Min.
.1M HCl	8.7	13	14.8	15.7	16.2
.2M HCl	14	21.2	24	25.2	25.9
.3M HCl	27	35	37	38.1	39
.4M HCl	37.5	46	48.2	49	49.6
.1M $HC_2H_3O_2$	2	3	3.5	4	4.3
.2M $HC_2H_3O_2$	9.7	15.7	18.7	20.4	21.4
.3M $HC_2H_3O_2$	14.5	25	30	32.2	34.2
.4M $HC_2H_3O_2$	15	28	34	37.5	39.7

Appendix 10C
CAT Test for LC-14

Name____________________
Section__________________
Date____________________
Code LC14-

QZ is a hypothetical compound, which is a solid at room temperature. When the solid is tested with litmus paper, there is no change in litmus color. A test for conductivity, shows that the solid does not conduct electricity. A water solution of the compound causes litmus to change from blue to pink, and it conducts electricity.

1. What does this information tell you about the nature of this compound?

2. Explain the difference in conductivity between the solid and solution.

3. Explain the difference in litmus test between the solid and solution.

Name
Section
Date
Code LC 14

Following are six compounds whose water solution have been tested for conductivity and with litmus. Indicate (by circling A, B or N) if each compound is an acid, a base, or a neutral compound. Also indicate what ions will be in the solution.

	Compounds	Conducts	Litmus	A B N	Ions Present
1	$Sr(OH)_2$	Yes	Red → Blue	A B N	
2	$PO(OH)_3$	Yes	Blue → Red	A B N	
3	HLiO	Yes	Red → Blue	A B N	
4	$Cu(OH)_2$	No	Red → Blue	A B N	
5	$SO_2(OH)_2$	Yes	Blue → Red	A B N	
6	CH_3OH	No	No Change	A B N	

10C-3

Rationale, Construction and Grading Criteria for the CAT Tests for Learning Cycle 14

The central concept for Learning Cycle 14 was: (1) Acids are compounds that release hydrogen ions in a water solution. Acids, as solids, are compounds whose formulas contain hydrogen ions, (2) Bases are compounds that release hydroxide ions in a water solution. Bases, as solids, are compounds whose formulas contain hydroxide ions. In several of the previous investigations students have carried out conductivity and litmus paper tests on a multitude of substances. The concept of the preceding investigation was that soluble ionic substances dissolve because water interacts with the ions of the solids causing the ions to separate and mix homogeneously. Therefore, the students are aware that for a substance to conduct an electrical current the presence of ions is necessary. The students are familiar with litmus paper indications.

There were two CAT tests developed for LC-14. The pre-learning cycle test (Appendix 10C-1) consisted of three questions concerning a hypothetical compound whose description has a solid and solution, as well as test results for conductivity and litmus paper, were described prior to the questions. To answer the questions the student would need to rely on the background experience developed in the course. The student's understanding of what is necessary for a substance to conduct was determined by these questions. The post-learning cycle test (Appendix 10C-12) dealt with the same topic however a different format was used. The students were given a list of six compounds and test results for conductivity and litmus paper for water solutions of these six compounds. The question was for the student to indicate whether the substance was acidic, basic, or neutral, and also to list the ions that would be present in each solution. A complicating factor for many students was that the formulas for some of the compounds were not written in the conventional style of positive ion followed by the negative ion. This CAT test was used again as a retention test approximately six weeks later.

The general grading criteria was described in Chapter Two of this report. The pre-learning cycle CAT test consisted of three questions each of which was scored separately. The specific grading criteria for each question will be listed followed by example responses of each criterion.

Question 1 - Criterion 3

The compound ionizes forming hydrogen ions in a water solution.

Question 1 - Criterion 2

The compound is a acid.

Question 1 - Criterion 1

The student fails to recognize that this is an acidic substance.

Question 1 - Criterion 0

No response or nonsense answer.

There were not any Criterion 3 responses for Question 1. This CAT test was given only as a pre-learning cycle test.

Examples of Criterion 2 Responses - Question 1

Response 1

When in solution it is an acid.

Response 2

The compound forms an acid solution with water that conducts electricity.

Response 3

This compound dissolves in water ionically. The molecules of the compound split into positive and negative ions in the water. The litmus change in solution indicates that it is an acid.

Response 4

The compound is an electrolyte. It dissolves in water by its ions splitting. It is also an acid.

Responses 1 and 2 were the most common explanations giver by the students.

Examples of Criterion 1 Responses - Question 1

Response 1

When the compound is added to water, there is a chemical reaction which produces new products. (One which changes litmus paper and conducts electricity.)

Response 2

It reacts better when in liquid form. In solid state you cannot test because the particles aren't moving and in liquid form they are moving.

Response 3

It is soluble in water and forms a solution when dissolved.

Grading Criteria for Pre-Learning Cycle CAT

Question 2 Criterion 3

In a water solution water separates the solid into ions allowing for conductivity.

Question 2 - Criterion 2

The difference between the solid compound and its solution is that the solution will conduct. (The student does not have to identify that ions are present to receive a grade of 2.)

Question 2 - Criterion 1

(1) The student does not recognize the role of water in a solution.

(2) Water is the conducting media of a solution.

Question 2 - Criterion 0

No response or nonsense answer.

Example Responses of Criterion 3 - Question 2

Response 1

When the solid was added with the water to make the solution, the solid broke into ions which conducted electricity.

Response 2

When the solid is dissolved in water, the ions are free to move whereas they cannot move as well in a solid. Since they cannot move, they will not conduct electricity.

Response 3

In a solid the ions are packed together, so they can't move. In a solution they disassociate and are able to move around and carry a charge.

Examples of Criterion 2 Responses - Question 2

Response 1

It must be a solution to conduct and it's not a solution until combined with water.

Response 2

In the solid the particles were not moving about as much as in the solution. Since this was the case, they did not transfer or conduct energy.

Response 3

The solid itself does not conduct. Electricity does not flow through the dry particles, but the solution is a mixture of the solid and water which form together to produce a solution which does conduct.

Examples of Criterion 1 Responses - Question 2

Response 1

The solution was able to completely surround the conductivity apparatus and the solid was not.

Response 2

Well the solid compound didn't conduct because the molecules are not going around like they are in the liquid form of the compound.

Response 3

By definition an electrolyte is a substance whose water solution conducts electricity. The solid won't allow a flow of electrons but when put in water the water acts as a medium to allow for current.

Response 4

When the solid is tested as a solution the water acts as a conductor.

Grading Criteria for Pre-Learning Cycle CAT

Question 3 - Criterion 3

The difference in litmus test between the solid and its solution is that in the solution of Q2 water separates the compound into ions and the hydrogen ion is present.

Question 3 - Criterion 2

A solution is necessary for litmus paper to indicate the presence of an acid. (The student does not have to specify the hydrogen ion.)

Question 3 - Criterion 1

(1) The student attributes litmus reaction to the presence of water.

(2) The answer contains other misconceptions.

(3) The student fails to recognize the role of water in a solution.

There were not any Criterion 3 responses given for question 3. This CAT test was only given as a pre-learning cycle evaluation.

Examples of Criterion 2 Responses - Question 3

Response 1

The substance had to be dissolved (made into a solution) for the reaction in litmus paper to occur.

Response 2

The acid characteristics are released from the molecules when the molecules are broken down by dissolving.

Response 3

In the solution perhaps one of the ions causes the change, while in the solid the ions would not be free to do this.

Response 4

Apparently the litmus test relies on the presence of ions. Therefore, since the solid is made of molecules, the solution is necessary in order to do the ionic bit with the paper.

Examples of Criterion 1 Responses - Question 3

Response 1

The solid does not have any moisture for the litmus to absorb. The solution causes the change because it can absorb some of the solid particles.

Response 2

A dry powder can't soak into the litmus, a wet solution will.

Response 3

When the solid was added with the water, a chemical reaction took place and produced a product that would change litmus paper.

Response 4

Water causes the solid to become an acid.

Grading Criteria for Post-Learning Cycle CAT 14

Following are six compounds whose water solution have been tested for conductivity and with litmus. Indicate (by circling A, B, or N) if each compound is an acid, a base, or a neutral compound. Also indicate what ions will be in the solution.

	Compounds	Conducts	Litmus	A B N	Ions Present
1	$Sr(OH)_2$	Yes	Red → Blue	A [✓ B] N	Sr^{2+}, OH^-
2	$PO(OH)_3$	Yes	Blue → Red	[✓ A] B N	H_2PO4- or $HPO4^{2-}$ H+ and $PO4^{3-}$, or
3	HLiO	Yes	Red → Blue	A [✓ B] N	Li^{+1}, OH^-
4	$Cu(OH)_2$	No	Red → Blue	A [✓ B] N	Cu^{2+}, OH^-
5	$SO_2(OH)_2$	Yes	Blue → Red	[✓ A] B N	H^+ & SO_4^{2+} or HSO_4-
6	CH_3OH	No	No Change	A B [✓ N]	None

There were six scores given on this test each using the following guidelines.

Criterion 3

The correct identification of the acidic, basic, or neutral nature of the compound and the correct ions (also charge of the ions) that would be present.

Criterion 3

(1) The correct identification of the acidic, basic or neutral nature of the compound and the appropriate acid or base ion that would be present.

(2) The correct identification of the acidic, basic or neutral nature of the compound and the correct ions (without charge) that would be present.

(3) For line #6 if the nature of the compound is identified as neutral and no ions are listed.

Criterion 1

Incorrect identification of acidic, basic or neutral nature of the compound or incorrect ions listed.

Criterion 0

No response.

Examples of Criterion 3 Responses

	Compounds	Conducts	Litmus	A B N	Ions Present
1	$Sr(OH)_2$	Yes	Red → Blue	A [✓ B] N	Sr^{2+}, $2OH^-$
2	$PO(OH)_3$	Yes	Blue → Red	[✓ A] B N	H^+, $PO_4{}^{3-}$
3	HLiO	Yes	Red → Blue	A [✓ B] N	Li^+, OH^-
4	$Cu(OH)_2$	No	Red → Blue	A [✓ B] N	Cu^{2+}, $2OH^-$
5	$SO_2(OH)_2$	Yes	Blue → Red	[✓ A] B N	H^+, $SO_4{}^{2-}$
6	CH_3OH	No	No Change	A B [✓ N]	none

Examples of Criterion 1 Responses

	Compounds	Conducts	Litmus	A B N	Ions Present
1	$Sr(OH)_2$	Yes	Red → Blue	A [✓ B] N	Sr, OH
2	$PO(OH)_3$	Yes	Blue → Red	[✓ A] B N	H^+, $O^{-2}P^{5+}$
3	HLiO	Yes	Red → Blue	A [✓ B] N	Li, OH
4	$Cu(OH)_2$	No	Red → Blue	A [✓ B] N	Cu, OH
5	$SO_2(OH)_2$	Yes	Blue → Red	[✓ A] B N	H^+ O^{2-} $S6^+$
6	CH_3OH	No	No Change	A B [✓ N]	none

Examples of Criterion 1 Responses

	Compounds	Conducts	Litmus	A B N	Ions Present
1	$Sr(OH)_2$	Yes	Red → Blue	A [✓ B] N	Sr^{2+}
2	$PO(OH)_3$	Yes	Blue → Red	[✓ A] B N	PO^{3+} $3OH^-$
3	HLiO	Yes	Red → Blue	A [✓ B] N	H^+ Li^+ O^{2-}
4	$Cu(OH)_2$	No	Red → Blue	A B [✓ N]	No ions
5	$SO_2(OH)_2$	Yes	Blue → Red	[✓ A] B N	SO_2^{2-} $2OH^-$
6	CH_3OH	No	No Change	A B [✓ N]	CH_3^+ OH^-

Appendix 10D

BAR Written Comments

BAR Written Comments

LC- 14 CLASS 111 N = 24, 24 with comments

Lesson Control - Control

	+	0	-	Comments
Lab	17			
Discussion	1			
Demo				
Questions			4	
Problems				
Readings	1		6	
Lecture			1	
	19		11	

	#	Comments
I'm Confused	6	
Activities Not Logical		
Too fast	3	
Too slow		
I Understand	3	
I Like	4	
I Don't Like	1	
Activities Are Logical		
	17	

Quotes: "I liked the labs the best, and I like lectures the least (although that's where I learn the most)."

"I liked the lab the most because I get more out of it. I didn't like the readings because it didn't explain the topic very well. I didn't understand the reasons for the answers on the worksheet."

BAR Written Comments

LC- 14 CLASS 114 N = 16 , 15 with comments

Lesson Control - T.

	+	0	-	Comments
Lab				Need Labs - 3
Discussion	2		3	
Demo				
Questions			1	
Problems				
Readings				
Lecture	1		2	
	3		6	

	#	Comments
I'm Confused	4	
Activities Not Logical		
Too fast	1	
Too slow		
I Understand		
I Like	1	
I Don't Like	1	
Activities Are Logical		
	7	

Quotes: "I liked best that this was a pretty simple concept. It was easy to understand and we used older terms we were familiar with. I hated that we weren't in lab. We are never in lab anymore, but 1st block is all the time. I thought chemistry was a lab class, but we are hardly ever there. That is the only thing I dislike about this unit."

"I liked the in-class discussion the least along with the over-head discussion. I didn't really like any of this because we didn't have any labs, just information given to us. This didn't really help me because after a while you lost my attention so I wasn't really listening."

10D-3

BAR Written Comments

LC- 14 CLASS 121 N = 20 , 13 with comments

Lesson Control - Control
extra

	+	0	-	Comments
Lab	9			
Discussion	1		2	
Demo				
Questions	1		2	Lab questions singled out
Problems			2	
Readings				
Lecture				
	11		6	

	#	Comments
I'm Confused	3	
Activities Not Logical	1	
Too fast		
Too slow	1	
I Understand	1	
I Like	2	
I Don't Like		
Activities Are Logical		
	8	

Quotes: "Looking at the data and having to draw my own conclusions was enjoyable."

10D-4

BAR Written Comments

LC- 14 CLASS 122 N = 20 , 19 with comments

Lesson Control - R

	+	0	-	Comments
Lab				
Discussion	4		1	
Demo	7			Teacher was goaded into doing Demo
Questions			1	
Problems				
Readings			1	
Lecture				
	11		3	

	#	Comments
I'm Confused	5	
Activities Not Logical	1	
Too fast	2	
Too slow		
I Understand	1	
I Like	5	
I Don't Like	1	
Activities Are Logical		
	15	

Quotes: "I like the demonstrations in class, but there needs to be a more ordered class discussion."

BAR Written Comments

LC- 14 CLASS 125 N = 23 , 23 with comments

Lesson Control - T_2

	+	0	-	Comments
Lab				No Labs - 3
Discussion	2		1	
Demo	7		1	
Questions				
Problems			2	
Readings				
Lecture	1			
	10		4	

	#	Comments
I'm Confused	6	
Activities Not Logical	1	
Too fast	3	
Too slow	1	
I Understand	1	
I Like	5	
I Don't Like	1	
Activities Are Logical	1	
	19	

Quotes: "I do not fully understand everything in this activity. We keep jumping from one new topic to the next, which makes it difficult to fully grasp an idea. Also we were asked to do worksheets before we were fully explained the idea. We were supposed to come up with our own theories on how acids and acids or bases and bases, based on our observations of labs or by our data, and if we could not figure it out we were counted off. It is difficult for me to pick up on ideas like that. I took chemistry in order to learn the ideas and theories behind chemistry not to play chemist."

10D-6

"I would have liked to have done a lab. The unit was fairly easy since the logic was easy to follow. I hope the rest are like this."

"As the year goes on it gets extremely boring to have so much discussion. This is tiresome and after awhile one just doesn't want to understand anymore. I think if we had gone through this more quickly and had not been interrupted (the review sheet, etc.) it would have been more interesting."

"I think that I liked this subject more than some of the previous ones. However, it is the same thing over again. I understand it fairly well in class and by my notes when I'm studying for a test, but when I take the test I fail it. This was a fairly interesting subject to learn about. I liked it okay."

"I like best the laboratory experiments conducted by Mr. Fix because I feel I can understand more if there is step-by-step explanation of each procedure. I think we ought to do a lab ourselves and then it be repeated by the instructor to further our understanding."

"I liked the investigation that dealt with the acid and base substances. I think it was the 1st experiment. This unit (or investigation) was really confusing because I really can't tell you what I learned. It went by too fast with not enough explanation."

"The part I liked the most about this investigation was the new information I learned. The part I liked the least would be the fact that we didn't do any labs, just demonstrations."

"I like the lectures. They seem to give you more of a conclusion rather than letting you totally draw your own."

"None of these exercises run in sequence and they aren't leading up to anything. We aren't sticking with a subject long enough for me to totally grasp it."